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ENGINEERING

INDEX ISSUE

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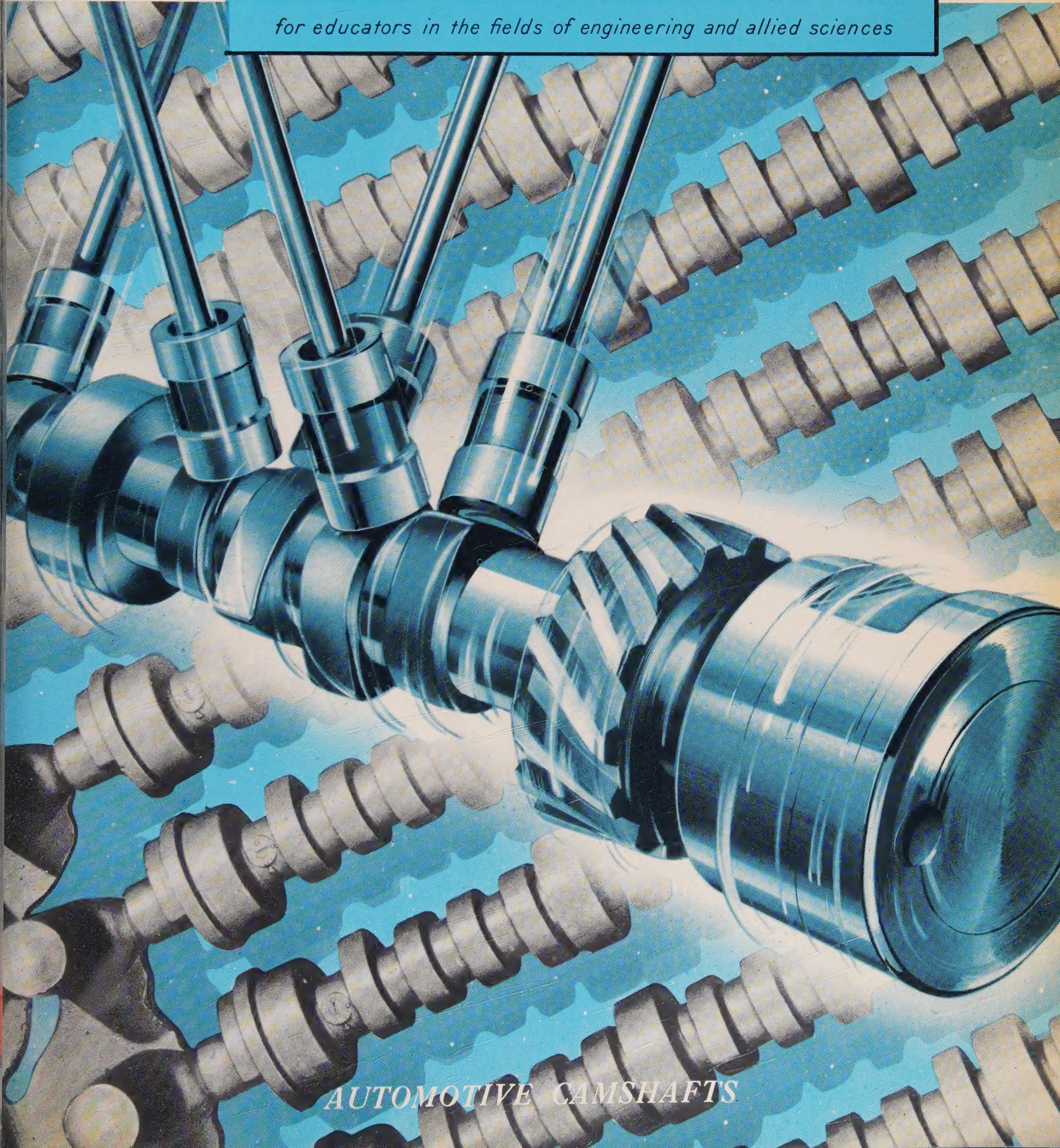
JOURNAL

for educators in the fields of engineering and allied sciences



AUTOMOTIVE CAMSHAFTS

Some Thoughts on Value

THE ESSENCE of the engineering profession is to be of value—collectively as a group and personally as individuals in the group. To be of value is to serve today so that the time spent will benefit mankind both now and in the future.

September is the beginning of the future until October comes along to make the opening of the 1956-1957 academic year a part of the past. September is a good time to take stock of the present so that the fullness of engineering qualities may be projected better into the future. It is well to look further ahead than to the end of the current semester or term so that these short-term milestones will fit neatly into a well-charted pathway from which there can be no returning.

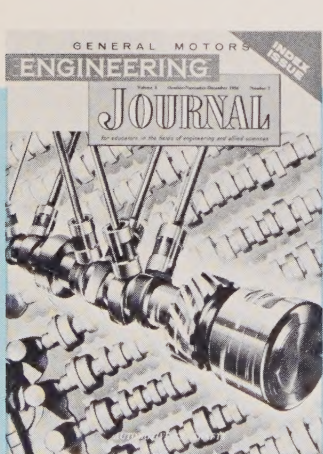
The material present is what it is largely because of the values projected by engineers of the past. They were at the root of a shortening of the work week, an increase in the standard of living and, indeed, were instrumental in spawning the design and productive strengths which have kept the nation safe from attack. Benefiting from the projected engineering of the past is a growing national population of more than 167 million people in more than 47 million households. It is a population with growing numerical strength among its young and also among those who have retired from active, full-time work. In the mid-range is a labor force now numbering about 64 million and increasing less rapidly than the total population.

Engineering adds values to materials and manpower. These values become beneficial to people largely because a labor force also adds its needed contribution to the plans of engineers. The pathway out ahead for engineering indicates an increasing need for the kind of advancement which will enable the labor force to produce more and more with no greater—or even less—exertion of human muscle power. We have become a nation having a great wealth of conveniences covering almost the whole range of time, places, and things in our everyday lives. These conveniences serve around the clock, starting with a musical device to awaken us in the morning and ending with a temperature control which, without attention, reduces the bedroom temperature just at bedtime. These conveniences extend from the kitchen to the factory, from the familiar automatic toaster to the newest hydraulic transfer machine. At every turn, engineers have succeeded in conserving man's muscle power and in increasing his mental performances through aids such as computers. To have merely the same quantities of these in the future is to have less for each individual because the gross product must be divided into a larger number of pieces in a growing population. The real challenge is an old one: to have more must not only produce more, produce more and more, because population is increasing faster t the labor force which must suppor

The engineer and engineering whole can be of value in the y ahead by preparing now to m technically and economically feas the means of manufacture which enable greater productivity with same effort; to design the new go which the growing population desire and need; to devise new w of servicing and distributing go to find the new materials which supplant those which are being pleted; and to improve the mean which the supply of available en can be maintained.

We are beginning today; the fu is filled with opportunity on ev side for the engineer and engineer to be of service and, therefore, value.

L. C. Goad,
Executive Vice Presid



THE COVER

The camshaft is a critical component in today's high-speed, high-compression engines. Recent metallurgical and mechanical design advances have been captured symbolically in the cover of this issue—another by artist John Tabb depicting developments in transportation.

Probably the most significant new development in the manufacture of automotive engine camshafts is the application of shell molding to replace "green" sand casting techniques. Shell cast camshafts, which form the background pattern of this cover, have cleaner and smoother surfaces, which prov the dimensional control required in toda automated machining facilities.

There has been progress, too, in the techni aspect of camshaft design. Modern camshaf made of alloy gray iron, are more rigid a durable than in the past. Modification in t cam contour resulting in high lift without increase in the dynamic loading was ma possible due to a better understanding of t acceleration characteristics affecting val motion.

CONTENTS

GENERAL MOTORS ENGINEERING JOURNAL

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Design of a Centrifugal Filmer for the Ultraviolet Irradiation of Liquids

By EGON BENESI
General Motors
Research Staff

Engineers help to speed production of polio vaccine

Engineers of General Motors Research Staff, working in cooperation with medical researchers of the Michael Reese Research Foundation, designed and developed a centrifugal device for the irradiation of whole blood, blood plasma, and vaccines. For several years this team of engineers and physicians searched the fundamentals of science, engineering, and medicine for a combination of laws which, when coupled with vast experience in their respective fields, would produce a relatively simple, yet effective, irradiating device for liquids. In principle the centrifugal filmer employs the fundamentals of dynamics and fluid mechanics to produce a uniformly micro-thin film of liquid and the properties of ultraviolet light to deactivate micro-organisms. While the Centrifilmer was conceived and developed originally for the irradiation of whole blood and blood plasma, it has found another important application—the rapid and effective irradiation of polio vaccine.

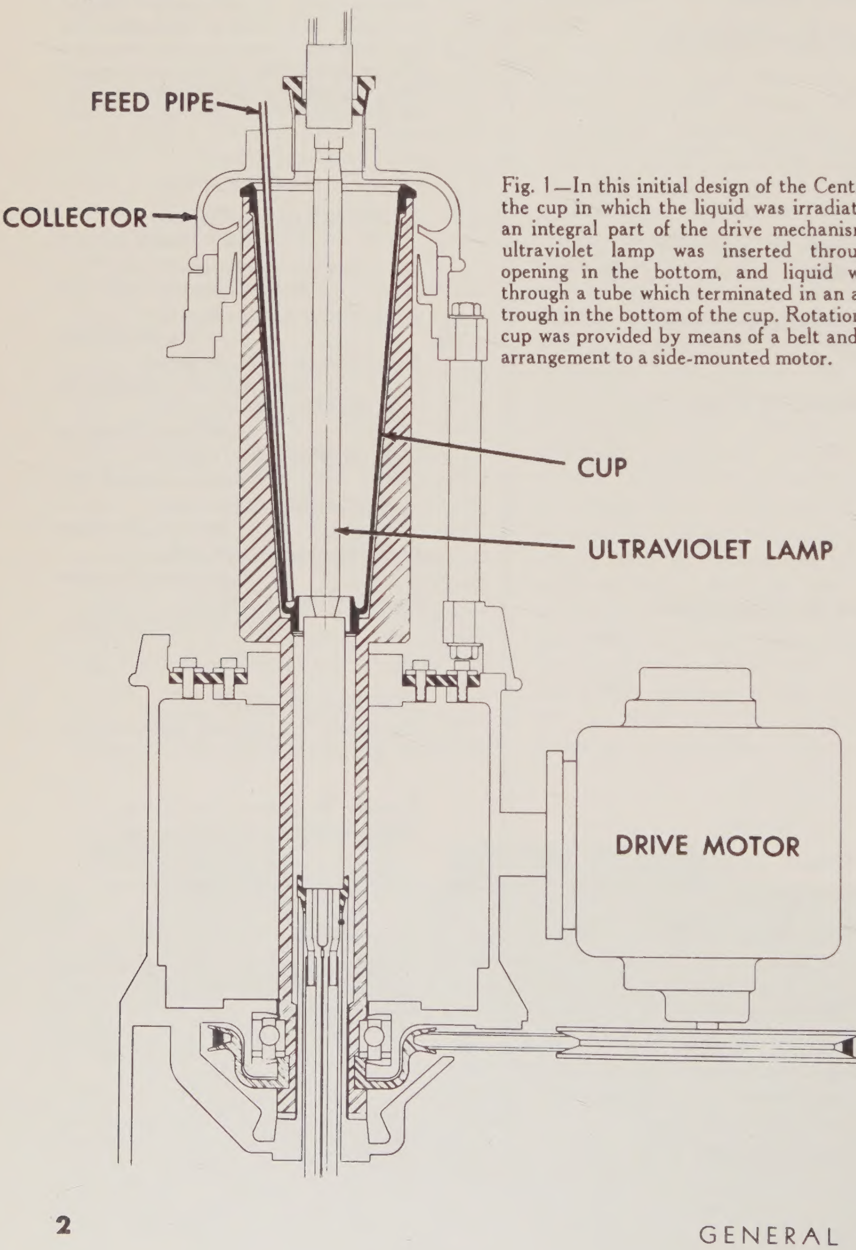


Fig. 1—In this initial design of the Centrifilmer the cup in which the liquid was irradiated was an integral part of the drive mechanism. The ultraviolet lamp was inserted through an opening in the bottom, and liquid was fed through a tube which terminated in an annular trough in the bottom of the cup. Rotation of the cup was provided by means of a belt and pulley arrangement to a side-mounted motor.

SOME years ago scientists of the Micha[illegible] Reese Research Foundation soug[illegible] the assistance of General Motors Resear[illegible] Staff engineers in connection with t[illegible] design of a device which would be effe[illegible] tive in sterilizing liquids, particular[illegible] whole blood and blood plasma. Wh[illegible] most everyone is familiar with the li[illegible] saving properties of these substance[illegible] occasionally they were contaminat[illegible] with infectious viruses causing a type [illegible] jaundice (hepatitis) which, in some case[illegible] proved fatal. Since ultraviolet light h[illegible] been used successfully to irradiate ot[illegible] substances, it was thought this techniq[illegible] could be applied to whole blood a[illegible] blood plasma. The principal proble[illegible] however, was to design a relatively simp[illegible] yet effective irradiating device wh[illegible] would inactivate any harmful micr[illegible] organisms in the whole blood witho[illegible] damaging the blood cells.

The Root of the Problem: Create a Uniform, Micro-Thin Layer of Liqui[illegible]

Basically, the Michael Reese Founda[illegible] tion researchers had as their objective [illegible] device which would create a micro-thi[illegible] layer of liquid, uniform in section, and [illegible] sufficient surface area so as to expose th[illegible] liquid to ultraviolet light for enough tim[illegible] to effect complete inactivation of infec[illegible] tious viruses. Actually this idea was no[illegible] new; others in the medical profession ha[illegible] tried similar techniques before but with[illegible] out complete success. The commo[illegible] stumbling blocks were: (a) lack of uni[illegible] formity in the liquid layer, (b) low capac[illegible] ity, or yield, (c) unsatisfactory dimen[illegible] sions for the exposed surface of the liquid[illegible] and (d) low irradiation efficiency of th[illegible] ultraviolet light source.

The principal task of GM's Researc[illegible] Staff engineers was to develop a vibration[illegible]

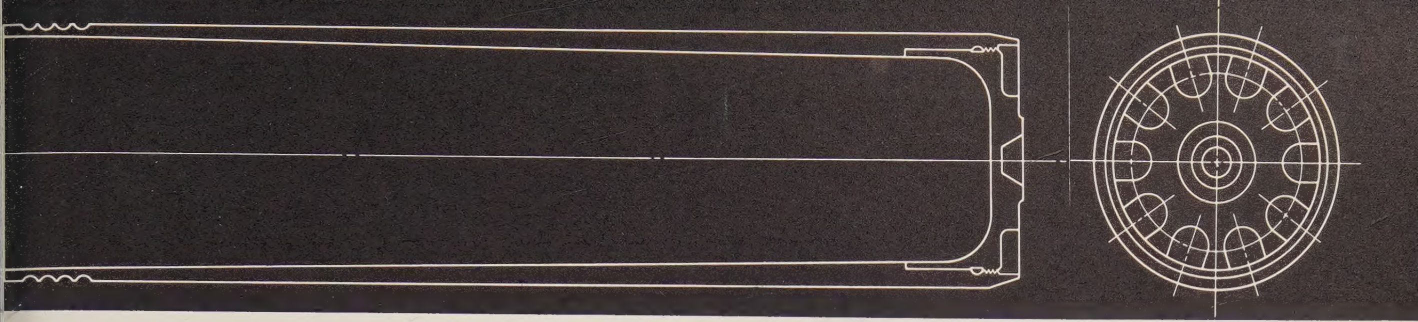


Fig. 2—The final cup design consisted of 2 stainless steel sections: the bottom or drive section, and the upper or conical tube section. The drive section was machined from solid stock, ground and polished, and attached to the tube section by a shrink-fit threaded joint. Rubber-covered driving lugs engaged recesses in the bottom of the cup. The entire inside surface was polished to a micro-finish to aid in producing a mechanically perfect liquid film surface and to facilitate cleaning after use. While other designs were tried, the simple, flat rim at the top with slightly eased edges was most satisfactory with regard to discharging the liquid into the collector ring.

free centrifugal device which would maintain a uniform, micro-thin liquid layer. Thus, with a background of knowledge and experience of more than 30 years in the design and construction of precision static and dynamic balancing machines they began to lay out a basic design for the irradiating device which was termed a "Centrifilmer."

Cup Design Involved the Fundamentals of Dynamics and Fluid Mechanics

Heart of the first Centrifilmer was a long, stainless steel cup. The inside surface of the cup was shaped essentially in the form of a frustrum of a cone. The included angle of the cone was small so that liquid introduced at the bottom would flow upward at the desired rate along the inner wall due to the centrifugal forces resulting from rotation of the cup. When the liquid reached the top, it discharged over the rim into a torus-like collector ring.

In this first model the cup was an integral part of the driving mechanism (Fig. 1). It was open at the bottom to provide for the insertion of a single ultraviolet lamp. Liquid was fed through a tube which terminated in an annular trough at the bottom of the cup. Since the single ultraviolet lamp did not provide sufficient irradiation effect, it was decided to try a lamp having more surface area and, instead of inserting it from the bottom, to suspend it from a holder at the top of the cup. This design change permitted closing the opening at the bottom of the cup. First attempts to do this involved special rubber stoppers, soldered or brazed metal plugs, and making the entire cup in 1 piece. This design, however, had certain disadvantages: the rubber stoppers were prone to leaks and chemical attack; the solder and brazing materials used to seal the metal plugs contaminated the liquid as a result of chemical action; and the 1-piece cup was too expensive and difficult to make.

The final cup design consisted of 2 stainless steel sections (total length 16 9/32 in., average inside diameter 3½ in.): the bottom or drive section and the upper or conical tube section (Fig. 2). The drive section was machined from solid stock, ground and polished, and attached to the tube section by a shrink-fit threaded section. The joint between the 2 sections was inspected using the fluorescent particle method to verify complete metal-to-metal contact. Finally, the whole inside surface of the cup was honed and polished to a micro-finish to aid in producing a mechanically perfect liquid film surface and to simplify cleaning after use.

An interesting parameter of the cup

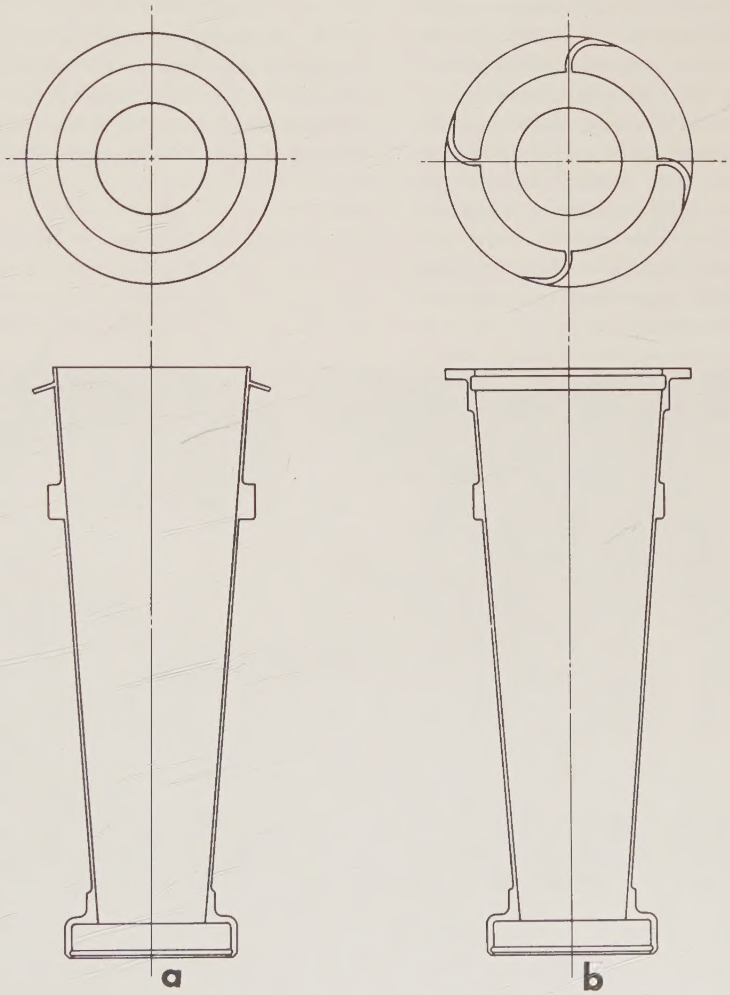


Fig. 3—One phase of the cup design had to do with the shape of the rim. In one early design (a) a splash shield built into the rim acted as a fan, causing the liquid to discharge at the wrong place on the rim. Another design (b) incorporated spiral outlets leading from a small recess; this gave uneven dispersion of the liquid. The simple, flat rim with slightly eased edges (Fig. 2) gave the most satisfactory results.

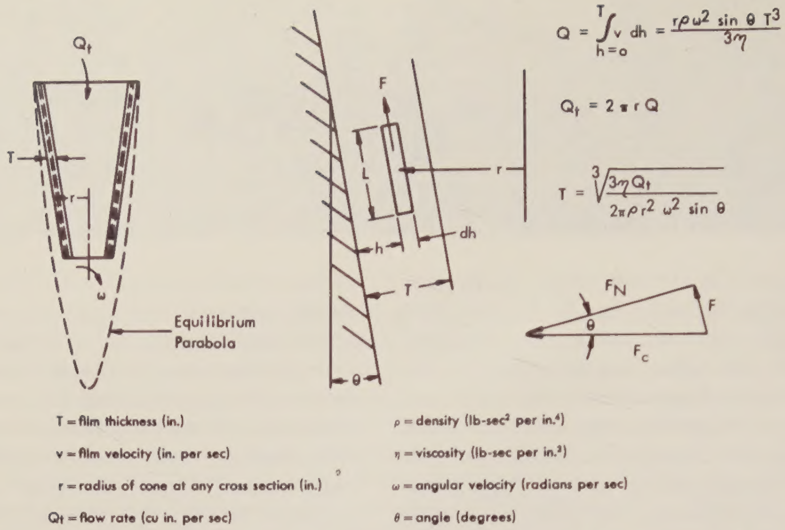


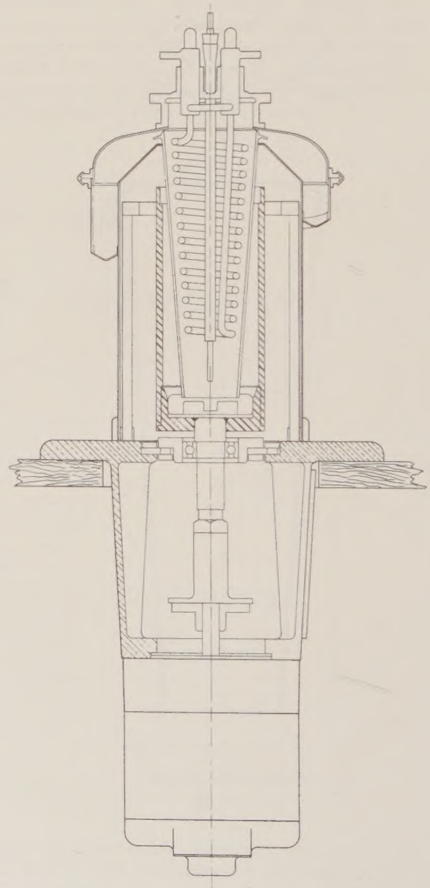
Fig. 4—Several factors were considered in designing the cup. Film thickness and velocity of flow depended upon the diameter, length, conical angle, and speed of rotation of the cup, as well as the viscosity, density, and flow rate of the liquid being introduced.

design had to do with the shape of the rim (Fig. 3). In one early design a splash shield built into the rim acted as a fan with the result that the liquid tended to remain in the cup and ultimately was discharged at the wrong place on the rim. Another design incorporated spiral outlets leading from a small recess at the top of the cup. This configuration proved unsatisfactory with regard to even dispersion of the liquid. A simple, flat rim with slightly eased edges gave the most satisfactory results.

There were several factors which entered into the design of the conical cup used in the Centrifilmer (Fig. 4). The thickness of the liquid layer and the velocity of flow up the inside wall of the cup depended upon the diameter, length, conical angle (2° included angle in final design), and rotational speed of the cup, as well as the viscosity, density, and flow rate of the liquid being introduced. These factors were relatively simple to control; it was in the solving of problems related to additional requirements of the device that GM researchers made significant contributions. These requirements were that the liquid layer be of uniform thickness throughout its cross section, that the surface be smooth and completely free of any ripples, and that the film would wet the entire inside wall of the cup. The key to meeting these requirements was in eliminating any vibration and unbalance forces in the Centrifilmer assembly. These aspects of the Centrifilmer are discussed under the heading *Vibration and Unbalance Forces*.

Design of the Ultraviolet Lamp and Lampholder

The capacity of the Centrifilmer depended primarily upon the maximum velocity of the liquid film which would still permit adequate exposure to a given ultraviolet lamp. In this respect the lamp,



too, was a vital component in the over design. The objective, then, in designi the lamp was to get maximum irradi tion efficiency consistent with the spa limitations imposed by an efficient cu design. There had to be complete assu ance that no infectious particle cou escape exposure to the ultraviolet ray Ultraviolet rays have very low penetra ing characteristics in most liquids, y over-exposure in the case of some liquid such as whole blood, results in damag of the cell structure.

In the first design, a single-tube lam was used. As pointed out earlier, th lamp was inserted into the cup throug an opening in the bottom. The lam extended below the bottom of the cup a holder where the required electric connections were made. Not only was found that this type of lamp had insuffi cient radiation capacity but also that complicated the cup design in that a annular trough had to be provided at th base of the cup into which the liqui could be introduced.

The second type of lamp which wa tried consisted of a spiral tube which pro vided a large irradiating area but wa

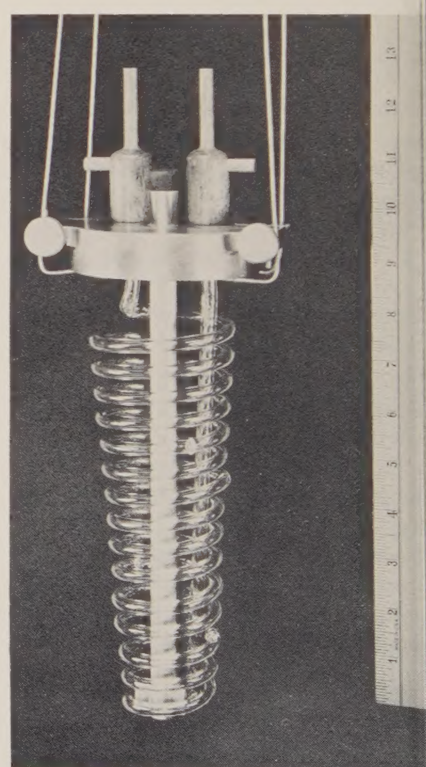


Fig. 5—The single-tube lamp used in the first model of the Centrifilmer did not provide sufficient irradiation effect. The spiral design shown here was the second which was tried. It was too expensive and fragile.

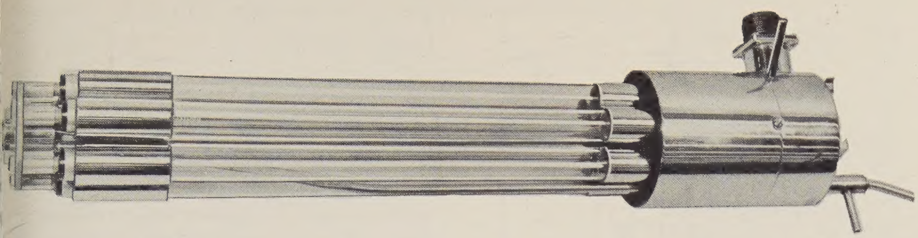


Fig. 6—The final lamp design consisted of 6 ultraviolet tubes arranged in a circular pattern. Six cooling water tubes were located in a similar pattern behind the lamps. This arrangement afforded an inexpensive, efficient lamp which could be controlled easily for correct intensity.

too expensive and fragile (Fig. 5). However, this lamp could be suspended into the cup from the top, eliminating the opening at the bottom and permitting the use of a direct drive in rotating the cup.

The third design, and the one currently being used, consisted of 6 tubular-type lamps arranged in a circular pattern. This arrangement afforded an inexpensive, efficient light source which could be controlled readily for correct intensity (Fig. 6). In addition to the lamps, 6 cooling water tubes were installed in the same pattern directly behind the lamps. These tubes formed the center core of the lampholder in that they held the head and foot supporting chambers together. Two copper bushings, attached to each water tube, acted as positioning devices for the lamps. These bushings also aided in the transfer of heat from the lamps to the cooling water. The water tubes were made of nickel-plated brass, as were the supporting chambers which hold them together.

The Introduction and Discharge of Liquid

The basic concept of the Centrifilmer dictated that the liquid being irradiated must be introduced at the bottom of the conical cup. This was accomplished in the first model through a small, stainless steel tube inserted into the cup through the top cover and which extended to the annular trough at the bottom (Fig. 1). This feed tube was encased in a larger diameter tube, also of stainless steel, which fed a continuous supply of nitrogen to maintain an inert atmosphere in the unit as a means of preventing contamination of the liquid through ionization of the oxygen in the air. In subsequent designs the concentric feed and nitrogen supply tubes were positioned vertically in the center of the ultraviolet lamp. In the final developmental stages of the Centrifilmer, however, it was found that a modified version of the original scheme permitted the installation of a photoelectric tube to monitor the intensity of the 6 ultraviolet lamps.

Upon reaching the rim of the cup, the liquid discharged horizontally across the flat surface of the rim, essentially in pinwheel fashion (Fig. 7), into a torus-like collector which was attached to the cover by means of a clamping ring. In designing the collector-cover it was vital that the liquid strike the cover in such a way that the liquid (particularly whole blood) would not be mechanically injured as a result of the centrifugal forces involved. Deflection had to be gentle to prevent foaming action or precipitation in the case of blood plasma. Capacity of the collector-cover had to be sufficient to maintain smooth discharge.

These requirements were met by highly polishing the interior surface of the collector-cover and by so shaping the cover that the angle of impact of the liquid was nearly tangential. Capacity was determined by the depth of the collector ring.

Drive Mechanism

The basic requirement of a smooth, uniform, micro-thin film of liquid in the cup of the Centrifilmer presupposed a drive mechanism free of vibration and unbalance forces. Due to limitations imposed by the ultraviolet lamp, the drive mechanism on early models of the Centrifilmer was integrated with the cup. A pulley and belt arrangement was used to couple the mechanism to a side-mounted motor (Fig. 1). This arrangement was unsatisfactory because it created a complex problem in eliminating unbalance forces. Re-designing the lamp and lampholder so that it could be suspended in the cup not only permitted separating the cup from the drive mechanism but also permitted the motor to be mounted axially below the cup, eliminating the need for the pulley and belt drive.

In the final design an induction motor was used to drive the cup at 1,750 rpm through an adapter having 2 rubber-covered lugs which engaged recesses in the bottom of the cup (Fig. 8). A Nylon ball-joint in the adapter served to support the cup, as well as to permit the cup to seek an equilibrium position. The drive

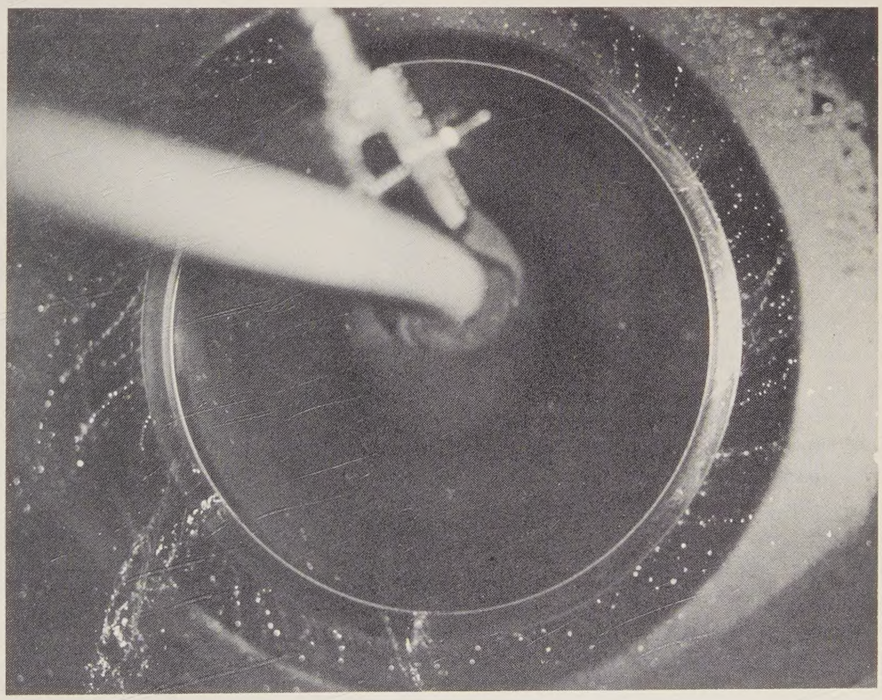
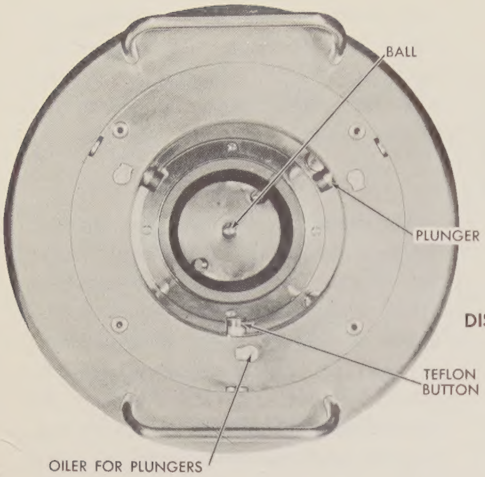


Fig. 7—Liquid is discharged across the flat rim of the cup, essentially in pinwheel fashion.



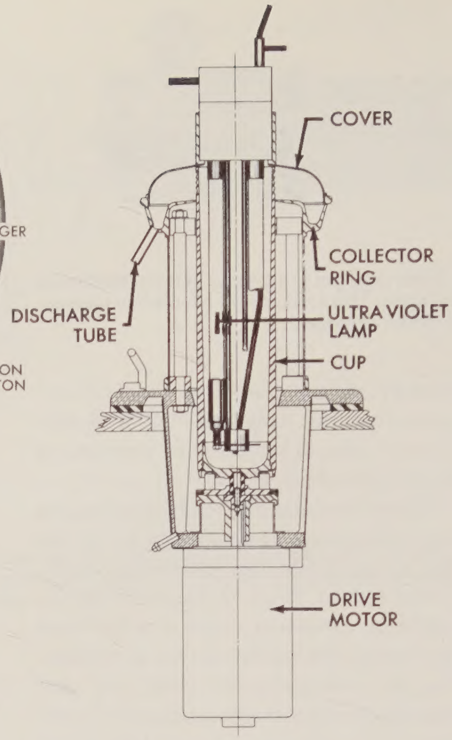


Fig. 8—In the final design of the Centrifilmer (right) an induction motor was mounted axially below the cup. Mechanical drive was through 2 rubber-covered lugs which engaged recesses in the bottom of the cup. A ball-joint thrust bearing (left) made of Nylon was used to support the cup, as well as to permit it to seek an equilibrium position. Three spring-mounted Teflon pads impregnated with graphite were located 120° apart in a ring which surrounds the top of the cup as a means of steadying it during operation.

motor was connected to the adapter by inserting the motor shaft into a close fitting sleeve in the adapter. A key and set screws insured a positive drive between the shaft and adapter, and the close fit between the shaft and sleeve minimized run-out.

Nylon was chosen because a steel ball proved to be too noisy. Slight high-frequency torsional vibrations during starting as a result of small relative motion between the cup and ball caused this noise. Nylon dampened these vibrations and also provided certain lubricating characteristics between the 2 surfaces. The adapter was made in 2 sections locked in place by set screws to permit proper centering. Also, the adapter was designed so that it could be raised or lowered on the motor shaft to provide correct positioning of the cup relative to the cover.

Three spring-mounted Teflon pads impregnated with graphite were located 120° apart in a ring which surrounds the top of the cup as a means of steadying the cup during operation. Since the cup rotated in a state of labile equilibrium, precession which normally would occur was avoided by introducing a silicon oil mixture in the piston-cylinder type holders behind the Teflon pads. This treatment created sufficient damping forces to keep the cup rotating truly around its mass axis.

A 100-ohm resistor circuit was used in order to obtain somewhat slower starting characteristics, thus avoiding not only an occasional slight lifting of the cup from the ball-joint thrust bearing but possible impact as well.

Vibration and Unbalance Forces

The stainless steel cup in the Centrifilmer was designed to rotate on its mass axis, thus minimizing problems in connection with vibration and unbalance forces. The normal operating speed of 1,750 rpm was considerably higher than the natural frequency of vibration of the entire rotating mass. Since the cup was designed to rotate as a freely suspended unit, the problem of producing a vibration-free device was resolved into one of balancing each rotating part dynamically.

Balancing of the Centrifilmer was carried out on a progressive basis; that is, each rotating part was balanced in succession as an integral part of the whole rotating assembly, beginning with the drive motor. The armature and shaft bearings were removed from the motor and dynamically balanced in a machine designed and built by Research Staff engineers (Fig. 9). The adapter was installed on the armature shaft and the assembly balanced again on the same dynamic balancing machine. During this operation the ball-joint thrust bearing in the adapter was checked for run-out. At this point the motor was reassembled and installed in the Centrifilmer. Bal-

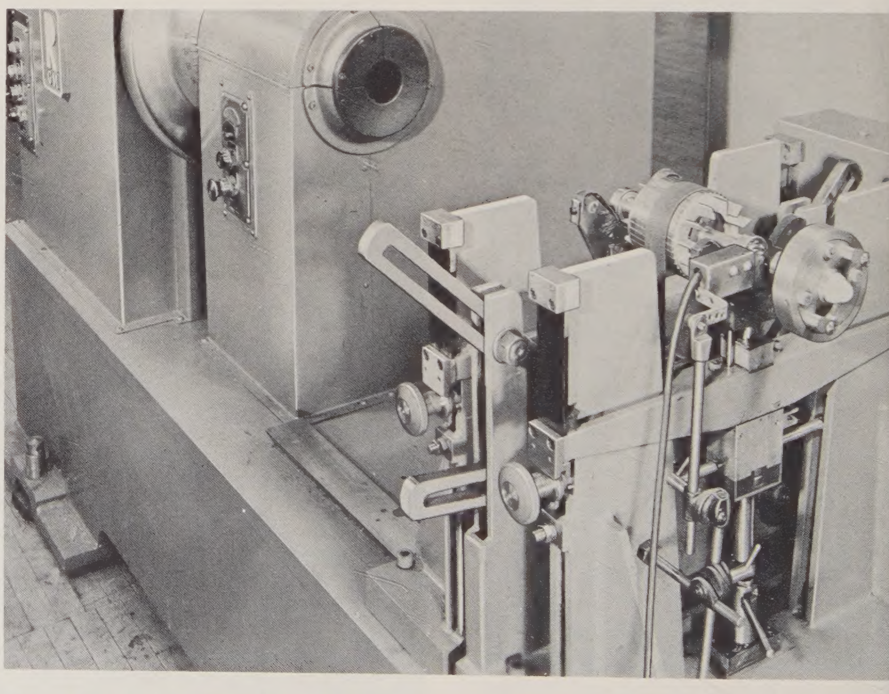


Fig. 9—This horizontal-type universal dynamic balancing machine was designed and built by GM Research Staff engineers to balance rotating parts, such as crankshafts, pulleys, and generator rotors used in passenger cars. The motor armature and drive adapter of the Centrifilmer are shown being balanced in this machine, which is capable of detecting unbalance forces as small as 0.01 oz-in., even less for smaller parts.

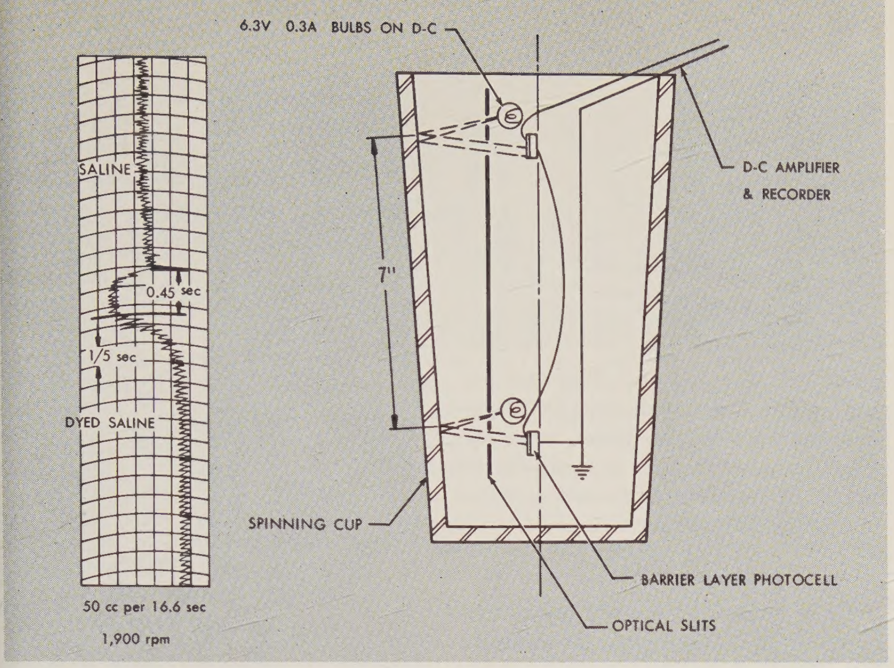


Fig. 10—Shown here is a schematic diagram of the instrument developed especially to determine the rate of flow of the liquid film. Two photoelectric cells were mounted 7 in. apart in a metal container. Optical slits were made in the wall of the container opposite each photoelectric cell and its corresponding light source so that light from the lamp would be reflected by the surface of the liquid into the photoelectric cell. By changing the color of the liquid being fed into the cup, the time of flow between the 2 photoelectric cell reference points could be measured. Average time of flow was 2/5 sec at a flow rate of about 50 cc per min.

ancing of the cup was done in the Centrifilmer unit. A crystal-type pickup, mounted to probe the inside surface of the cup approximately 1 in. from the top rim, was used to indicate the amount and location of any unbalance on the screen of a cathode-ray oscilloscope. Balance was effected by drilling a series of small depressions in the outside surface of the cup at the heavy point.

This technique not only produced a well-balanced assembly but also permitted cups to be transferred from one machine to another at will, since each cup of itself was in perfect balance.

Performance Testing to Verify Meeting Design Criteria

As various models of the Centrifilmer were built, it was essential to know whether the device could meet design specifications for film thickness, total capacity, flow rate necessary to obtain continuous wetting of the cup at various film thicknesses, and efficiency of irradiation.

As mentioned before, the completeness of irradiation of each particle is a function of the intensity of the ultraviolet light, film thickness, and length of exposure. The factors governing both film thickness and velocity were the flow rate into the cup, included angle of the cup, rotational speed, and the viscosity and density of the liquid. To verify design calculations of film velocity, GM researchers designed and built a special instrument to measure flow rate (Fig. 10). The instrument consisted of 2 photoelectric cells mounted 7 in. apart in a cylindrical metal tube. Optical slits were made in the tube opposite each photoelectric cell and its light source so that light from the lamp would be reflected by the surface of the liquid into the photoelectric cell. This assembly was suspended into the center of the cup. A saline solution was fed into the cup to establish a continuous liquid film on the inside wall (Fig. 11). A second feed tube was inserted into the cup to supply a dyed saline solution. In changing from the clear liquid to the one containing the dye, the photoelectric cells sensed the change in color by a change in the intensity of the reflected light. Signals from the photoelectric cells were fed into a recorder which, by means of a continuous graphic record, measured the time required for the film to travel up the wall of the cup between the 2 photoelectric cell reference points (the liquid particles travel in a spiral path rather than in a straight line). The time of flow using a saline solution was found to be approximately 2/5 sec at an average flow rate of about 50 cc per min. Average thickness (17 microns) was determined by dividing the flow rate by the velocity of the liquid. These values were obtained at a rotational speed of 1,750 rpm. Thickness and velocity of the film varies, of course, depending upon the flow rate, density, and viscosity of the liquid being fed into the cup. In the case of polio vaccine, for example, a flow rate of approximately 600 cc per min results in a film thickness of about 75 microns. This thickness is considered a practical optimum for irradiating vaccines.

In order to make direct determinations

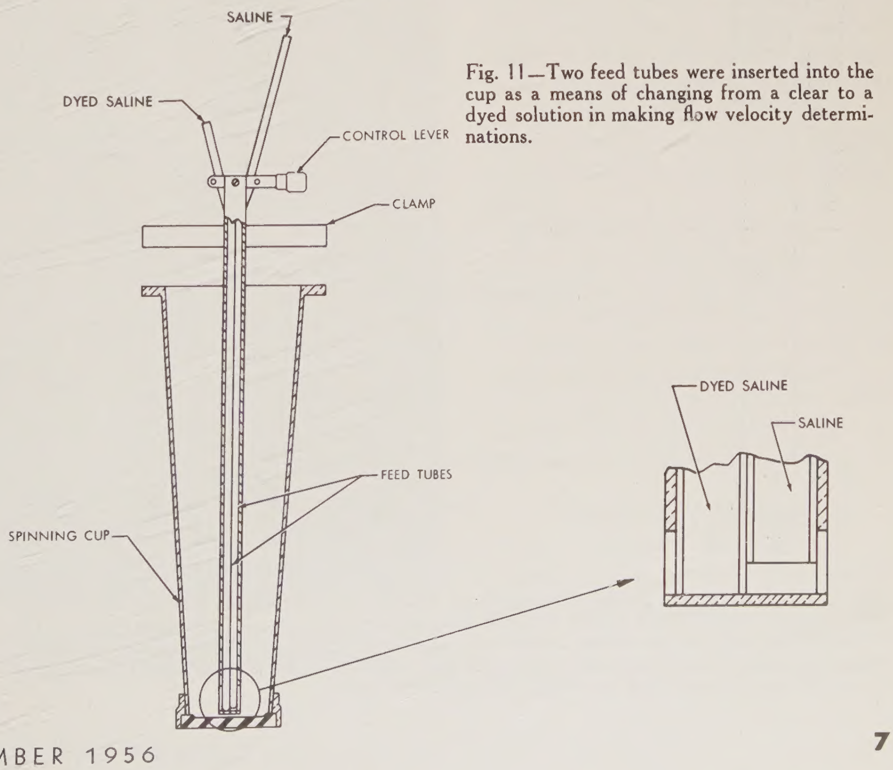


Fig. 11—Two feed tubes were inserted into the cup as a means of changing from a clear to a dyed solution in making flow velocity determinations.

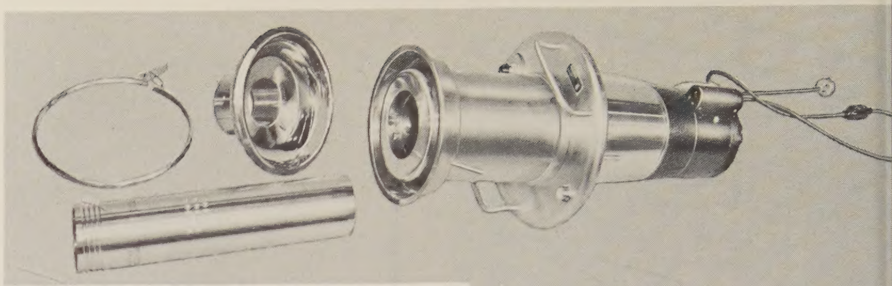
of film thickness, a special micrometer and electrical circuit arrangement was built (Fig. 12). When the pickup pointer touched the liquid surface, a signal was transmitted to an oscilloscope screen. The displacement of the pickup pointer from the wall of the cup was a measure of film thickness.

Film thickness measurements made by GM research engineers using this arrangement showed that the thickness varied from 2.5 microns to 25 microns depending upon the flow rate. Flow rates of liquids being introduced into the cup were adjusted to give optimum film thicknesses for each particular liquid.

Summary

The Centrifilmer (Fig. 13) is an example of the manner in which engineering know-how acquired in one field (in this case, the design of precision balancing machines) can be applied to problems in another. This simple, yet highly engineered device, solves a long-standing problem; for the first time, men in the pharmaceutical and medical research fields can produce unbroken fluid films sufficiently thin to be completely sterilized by irradiation.

To date, the Centrifilmer has been used for sterilizing whole blood; blood plasma; polio, rabies, and hoof and mouth vaccines; and for the preparation of ACTH. The Research Staff thus far has built 35 units. All of these have been sold to the Michael Reese Research Foundation, which has assumed responsibility for the distribution and application of the Centrifilmer.



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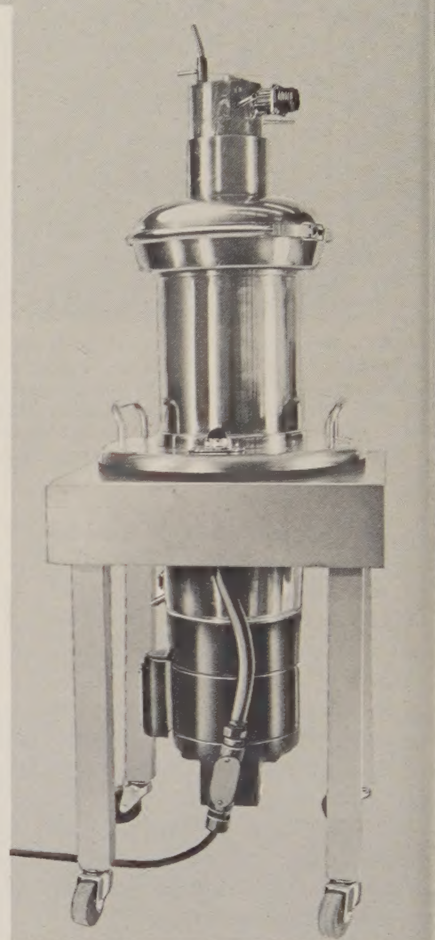


Fig. 13—Completely assembled, the Centrifilmer is about 34 in. long, including the drive motor and lampholder, and weighs 120 lb. Thirty-five of these machines have been built by General Motors for use in hospitals and laboratories to irradiate whole blood; blood plasma; polio, rabies, and hoof and mouth vaccines; and for the preparation of ACTH.

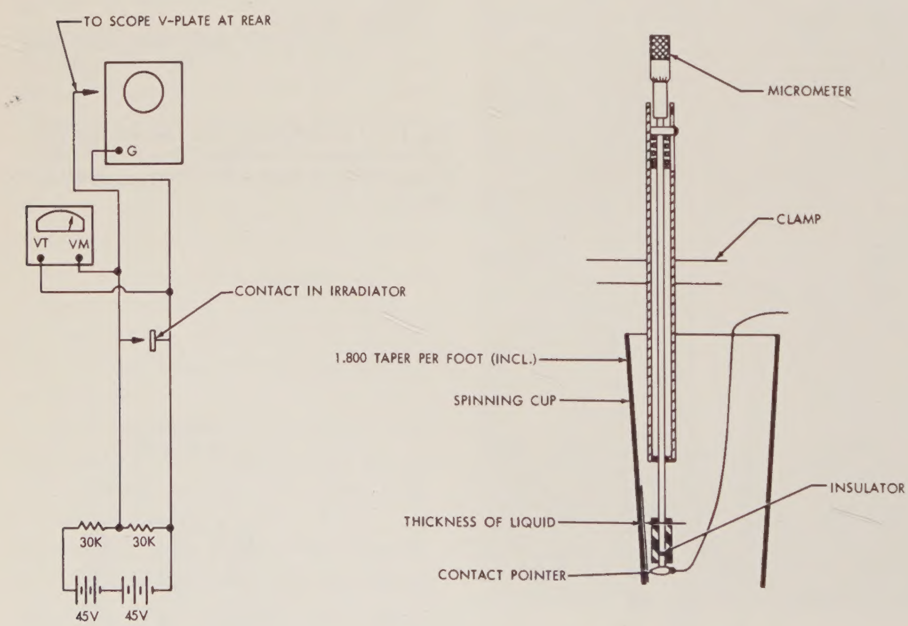


Fig. 12—A special micrometer and electrical circuit arrangement was designed and built by Research Staff engineers to make direct measurements of film thickness. When the contact pointer touched the surface of the liquid, a signal was transmitted to an oscilloscope screen. The displacement of the contact pointer from the wall of the cup was a measure of film thickness. Thickness varied from 2.5 microns to 25 microns depending upon the flow rate for each particular liquid.

Electrical Controls Make Industrial, Gas-Fired, Special Atmosphere Furnaces Safe

By CHARLES E. HUGGINS
Delco Products
Division

Special atmosphere furnaces are a vital part of many industrial heat treating operations. Since many of the atmosphere gases used are highly flammable, there is considerable fire and explosion hazard involved unless adequate controls are applied to minimize or entirely eliminate these hazards. While the primary consideration in the design and application of electrical controls for atmosphere furnaces is to prevent injury to personnel, a variety of other controls also are used to prevent damage to the furnace and equipment and to the work in process. Engineers at GM's Delco Products Division have devised a number of control circuits and devices to insure that the gas-fired atmosphere furnaces in their plant function safely and efficiently.

Safety first in the control of natural gas, air, and conditions inside the furnace

Special atmospheres are maintained in many heat-treating furnaces for such operations as annealing, bright annealing, bluing, and carburizing. In special atmosphere furnaces, the work chamber is heated in such a manner that product-of-combustion gases are not allowed to enter the chamber. When the work chamber reaches the proper temperature, a special atmosphere of the proper chemical composition is introduced to produce the desired metallurgical change in the work being treated.

Most special atmosphere furnaces are heated by gas-fired, radiant-tube burners. This type of burner consists of gas-tight, special-alloy tubes which pass through the furnace work chamber with both ends extending outside of the furnace (Fig. 1). A mixture of natural gas and air is introduced at one end of the tube, burned, and the product-of-combustion gases are exhausted from the opposite end. Heat radiating from the tube raises the temperature of the work chamber, and, since the tube is gas tight, no product-of-combustion gases can escape into the work chamber proper.

A gas generator is used to produce the atmosphere gas introduced into the work chamber of the furnace. The gas generator usually consists of a unit in which a controlled mixture of natural gas and air is burned to produce an atmosphere gas of the required chemical composition. For example, in a certain heat-treating operation, an atmosphere gas of the following analysis may be required:

Carbon dioxide (CO_2)	6 per cent
Carbon monoxide (CO)	9 per cent
Hydrogen (H_2)	10 per cent
Nitrogen (N_2)	75 per cent.

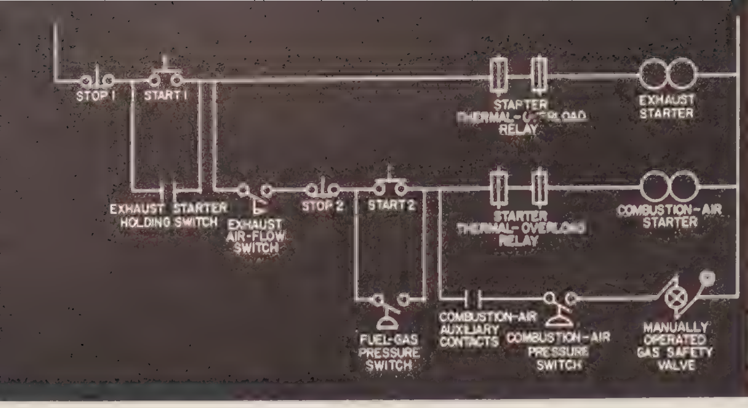
Fig. 1—This view of a large annealing furnace shows the ends of the radiant-tube burners and the burner pilot lights. Also visible are the combustion-air blower and the manifold-type distribution system to the burners.

Since natural gas is used both for heating the work chamber and for atmosphere charging, furnaces of this type can be an explosion hazard, particularly when introducing a flammable atmosphere gas into the work chamber. Ever present also is the hazard of the fuel gas in the generator used to produce the atmosphere gas. A great deal of extra care is taken to prevent an explosion from either source. The first consideration, of course, is for the protection of personnel in the furnace vicinity. Preventing the spoilage of the work in process in the furnace, damage to equipment, and production down-time are other considerations.

Special atmosphere furnaces may be grouped into 3 different physical types: (a) bath, (b) tray-pusher, and (c) continuous conveyor. The names indicate the various means by which the work enters and leaves the furnace. The following discussion will be limited to safety controls commonly employed on the continuous-conveyor type.

Electrical Controls Reduce Explosion Hazards

With respect to the fuel explosion hazard, the radiant-tube furnace is probably the safest type and, therefore, requires a minimum of electrical safety



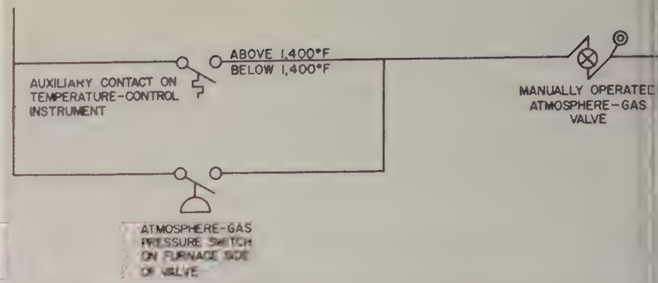


Fig. 2—Shown (above left) is a typical electrical circuit for controlling fuel gas and combustion air in an industrial heat treat furnace. The exhaust starter is energized by depressing switch "Start 1." An auxiliary contact of this starter switch provides a holding circuit. When the exhaust system is functioning properly, the exhaust air-flow switch closes automatically, allowing the combustion-air control circuit to be actuated. "Start 2" push button, which is within reach of the manually operated gas safety valve, is depressed, energizing the combustion-air starter. The "Start 2" switch must be held down until the following sequence of events occurs in the circuit: (a) the combustion-air auxiliary contacts close when the starter is energized; (b) the combustion-air blower having attained full speed, the combustion-air pressure switch is operated, closing its contacts in the circuit; (c) the holding coil of the gas safety valve is energized allowing the valve to be opened manually, the energized coil holding the valve open; and (d) the gas safety valve being open, the gas pressure operates the fuel-gas pressure switch, closing its contacts. This provides a holding circuit for the "Start 2" push button, which can be released. Ignition is provided for the radiant-tube burners in the form of fixed pilot flames of the total premixed type. It can be seen that, if the exhaust is stopped by push-button action or opening of the starter thermal-overload relays, all items will be de-energized and shut off. Also, if the combustion blower is stopped by push-button action, opening of the starter thermal-overload relays, circuit interruption by the exhaust air-flow switch, or the combustion-air-flow switch, the combustion-air starter and gas safety valve will be de-energized and shut off. If the fuel-gas pressure drops, the fuel-gas pressure switch will be released, opening the holding circuit. This will shut off the combustion air, and the gas safety valve will be de-energized and shut off. Of course, if the power is interrupted, all units are de-energized and shut off.

Fig. 3—In the event atmosphere-gas supply is interrupted while the furnace chamber is below 1,400° F, a control circuit is provided which locks out the atmosphere gas until the chamber temperature again reaches at least 1,400° F. When the furnace chamber is heated to 1,400° F, auxiliary contacts on the furnace temperature-controller close, energizing the holding coil of the gas valve. This allows the valve to be opened manually by the furnace operator, and the energized coil holds the valve open. The atmosphere gas then operates the pressure switch which is located on the furnace side of the manually operated valve. The contacts of this pressure switch provide a parallel circuit with the temperature contacts, keeping the atmosphere-gas valve energized if the furnace chamber temperature drops below 1,400° F. However, if the atmosphere gas is interrupted with the temperature-operated contacts open, the contacts of the pressure switch will open and de-energize the holding coil of the atmosphere-gas valve, closing the valve and locking out the atmosphere gas from the furnace.

equipment. The fuel supply and the combustion air are interlocked electrically so that the failure of either will shut off and lock out both the gas and air supplies to the burners. This requires that a manual-opening, automatic-closing, safety shut-off valve be placed in the fuel-gas supply line. Pressure switches are used in the circuit to indicate fuel-gas pressure and combustion-air pressure. In case of a power interruption, the fuel gas and the combustion air are shut off and locked out immediately (Fig. 2). Exhaust hoods are placed over the ends of the furnace and the radiant-tube burners to carry off any atmosphere gases that may escape from the ends of the furnace, as well as to carry off the products of combustion of the gas-fired burners.

To guard against fuel explosion hazards in the gas generator requires much the same type of controls as for the main furnace burners, with the exception of the exhaust circuit. The gas-generator burner operates continuously, and it is common practice to use a portable raw-gas pilot flame to provide the initial ignition. The gas-generator piping is arranged so that it can be vented outdoors by the operator prior to the establishment of normal operating conditions with the proper gas composition.

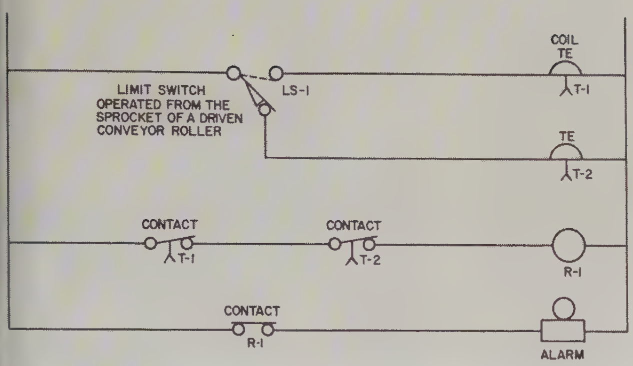
When the atmosphere gas being used is flammable, precautions must be taken when introducing it into the furnace chamber to prevent the formation of an explosive mixture. The valve or other device which controls the admission of a flammable atmosphere into the furnace is electrically interlocked with the furnace temperature-controller in such a way that the atmosphere gas cannot enter the furnace until the work chamber is above 1,400° F. Under these conditions the air in the furnace is "burned out" as the flammable atmosphere is admitted and before explosive mixtures can accumulate. This "burning out" continues until all air is purged from the furnace chamber. After the work chamber is purged, it is safe to continue to admit atmosphere gas even when the chamber temperature drops below 1,400° F. However, if the atmosphere-gas supply is interrupted with the chamber below this temperature, the controls lock out the atmosphere gas from the furnace, and the temperature is raised again to at least 1,400° F before the atmosphere gas is readmitted (Fig. 3).

Additional protection can be provided by the installation of a low-pressure vaporstat (0 in. to 7 in. water) between the gas generator and the furnace to sound an alarm if gas flow is interrupted. This control also can serve as an auxiliary contact on manual, magnetically operated gas valves. In the event that the gas valves might be accidentally closed, this contact may be used either to sound an alarm or to stop air pump motors on the gas generator.

Control Systems Safeguard Equipment and the Work in Process

While the primary consideration in designing electrical controls is to prevent explosion and injury to personnel, another consideration is the safeguarding of equipment and the work in process in the furnace.

Instruments are provided to detect temperatures in excess of normal, and the control circuit is arranged to shut off and lock out the fuel gas when this condition is detected. Assuming that the furnace is set to operate at 1,600° F, the contacts on the temperature-control instrument, which operate at 1,400° F, also can be used to indicate low temperatures. These are needed because temperatures which are too high will cause damage to the equipment and the work in process, while temperatures which are too low over a prolonged period of time will affect the quality of the work.



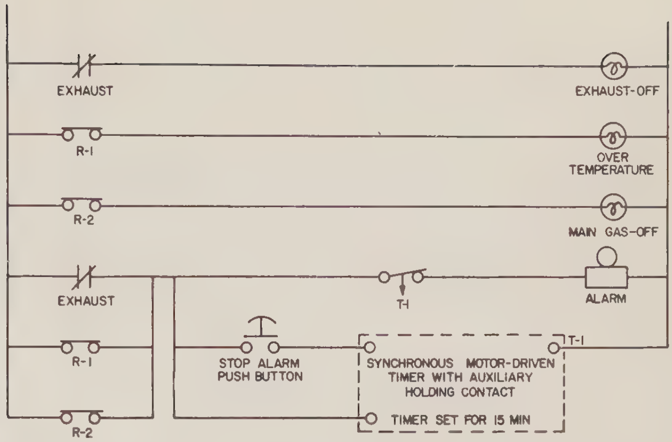


Fig. 4—The control circuit shown sounds an alarm if the furnace conveyor stops. The double-throw, snap-action limit switch LS-1 is mounted so that it is alternately operated and released by the teeth of the sprocket on a driven roller of the conveyor. Time-energized timers T-1 and T-2 are energized alternately on each throw of the limit switch and are set so as not to time out when the conveyor is operating at normal speed. If the conveyor is stopped for any reason, one of the timers will time out, de-energizing the relay R-1. The normally closed contacts of R-1 are used to signal that the conveyor has stopped.

Fig. 5—An alarm circuit similar to that used to indicate a conveyor stoppage is also used to reveal unsafe conditions, stoppages, or failures in other equipment on the furnace (above right). It can be seen in this circuit that, if the exhaust motor starter is de-energized, closing its normally closed interlocks, the "exhaust—off" pilot light is energized, and the alarm bell sounds. When the operator or maintenance man recognizes the trouble, he can stop the audible alarm by pressing the "stop alarm" push button. This energizes the timer T-1, which provides its own holding circuit, and opens the circuit to the alarm bell. Note, however, that the "exhaust—off" pilot light is still energized and indicating the cause of the trouble. This is one of the salient features of this circuit because it allows the operator to recognize that the trouble exists, shut off the audible alarm, and still have a visual indication of the cause of the trouble. Timer T-1 is set for approximately 15 min, and if the trouble has not been remedied by the end of this time, the timer contacts will close again, energizing the audible alarm. However, if the trouble is repaired and the exhaust starter is re-energized, the normally closed starter interlocks will open, de-energizing the pilot light and the timer T-1. When the timer T-1 resets, it will automatically restore the alarm bell circuit. From this it can be seen that the audible alarm can be silenced while fixing the trouble but that it is impossible to energize T-1 and lock out the audible alarm circuit unless the alarm has already sounded. The alarm circuit will work in the same manner regardless of the number of control items causing the alarm to sound because the pilot lights are in separate circuits and the audible alarm circuits are in parallel.

The control circuit is arranged to indicate when the heat-circulation or cooling fans are not operating. This is done by using the normally closed electrical interlocks of the starters for the various fan motors. If the heat-circulation fans are allowed to stop and remain stationary at elevated temperatures, the fan shafts tend to warp. If the cooling fans are stopped for any length of time, the work will emerge too hot to handle.

The rollers of the conveyor drive in the furnace must turn continuously when the furnace temperature is above 600° F. Even though the rollers are made of a special alloy steel, they will sag if allowed to remain stationary for an appreciable time while subjected to elevated temperatures. The fact that the rollers are turning is detected electrically (Fig. 4).

An alarm circuit is needed to call attention to the occurrence of unsafe conditions, stoppages, or failures in the operation of the equipment. Also, it is a great advantage to know what caused the alarm to sound, because the time saved in finding the trouble is reflected in less production down time and less maintenance labor charges. This indicates the need for a selective-alarm system. The method of providing this involves the installation of a single, audible alarm with individual pilot lights to indicate the cause or causes of the trouble (Fig. 5).

A comprehensive selective-alarm system for a conveyor-type atmosphere furnace might have pilot lights to indicate any or all of the following items:

- Exhaust—off
- Main burners—off
- Atmosphere-gas generator—off
- Over temperature
- Under temperature
- Conveyor—off
- Heat fans—off
- Cooling fans—off
- Discharge table not in position
- Doors stuck.

At first an alarm circuit may appear to involve many extra control items. However, a few extra contacts on existing equipment and an occasional relay will provide a great majority of the alarm circuits. Only in such cases as the roller conveyor circuit already described is much additional equipment required. The extra cost to provide a comprehensive selective-alarm circuit is usually only a small fraction of the total cost of a furnace (Fig. 6).

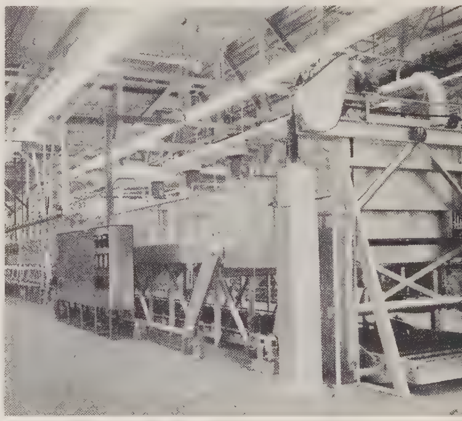
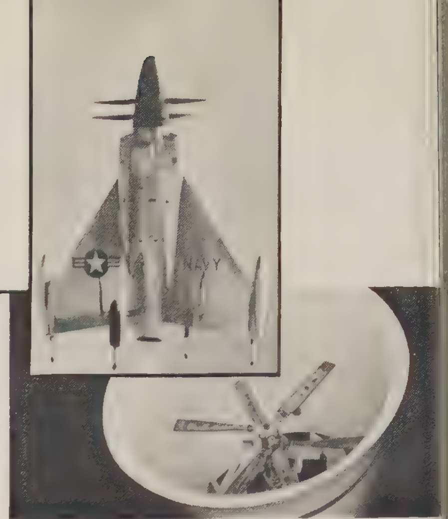


Fig. 6—This is a special atmosphere furnace used to anneal electric motor stators in the Kettering Plant of Delco Products Division, Dayton, Ohio. On the top-front of the control panel are the pilot lights of a selective-alarm system installed on this furnace.

Summary

When left up to an individual, safety is a relative matter based upon the individual's background, temperament, and training. Humans also are subject to fatigue, misjudgement, and loss of concentration when performing routine operations. On the other hand, properly designed safety control circuits perform their preset function time after time without error. Thus, complete, electrical safety controls, including those for equipment safety and an adequate alarm system, are a vital part of any industrial furnace installation.

A Program for the Developmental Testing of Turbo-Jet Aircraft Engines



A highly important phase of an overall turbo-jet engine design program is the series of developmental tests to which the engine is subjected prior to its release for production. Specific tests are first conducted in test cells on the ground to investigate the engine's performance and endurance characteristics at various simulated flight conditions. When the required performance and endurance life have been achieved, the engine then is tested under actual flight conditions. Also of importance in a developmental test program is the collection and processing of test data. The processing of raw information obtained from basic measurements of force, fluid flow, temperature, pressure, and rotational speed is accomplished in a data reduction system. The final step in the developmental program involves thorough analysis of test data and preparation of the engineering report.

THE term *testing* is generally used in connection with either research or developmental work. Research testing usually involves using known facts as a basis for establishing new concepts in the field of science. Developmental testing generally deals with the improvement of existing devices, materials, or mechanisms.

The present day turbo-jet aircraft engine is an example of a device which has benefitted from both research and developmental testing. The research testing phase consisted of applying the basic concept of Newton's third law of motion to the invention of a thermodynamic cycle which could be effectively used for propulsion. Today's turbo-jet engine with a thrust of 10,000 lb and above is the result of the continual improvement of a basic concept through extensive developmental testing.

At Allison Division developmental tests on turbo-jet aircraft engines are conducted both on the ground and in flight. These tests are aimed at continually improving engine performance and endurance.

After a new engine has been designed and its individual components tested, developmental testing of the completed engine is begun. Complete test engines are assembled and subjected first to a series of ground developmental tests. These tests include a wide range of simulated flight conditions, as well as ground operating performance conditions. After the engine meets service preflight requirements, it is subjected to actual flight tests.

Ground Developmental Test Conditions

The goal of turbo-jet engine developmental testing is to develop an engine having desirable performance characteristics and endurance. Developmental tests are established to obtain answers to such questions as: how does compressor efficiency vary with engine speed at sea level; how many hours will a set of turbine buckets run in an engine before failure; how does an engine operate under conditions of extreme temperature and pressure?

Ground developmental testing is often considered in 2 categories: (a) zero flight velocity and (b) positive flight velocity.

Zero flight velocity tests simulate conditions encountered by an engine in an aircraft at rest. This testing category includes engine starting and accelerating tests, engine operation at various simulated altitudes, engine operation at extreme temperatures, and engine operation at various attitudes (angle of engine centerline with respect to the horizontal).

Positive flight velocity developmental tests simulate conditions encountered by an engine in an aircraft in motion. It has been shown theoretically that the provision of appropriate stagnation (total) pressure conditions at the air inlet to the engine and required static pressure conditions at the engine exhaust are all that is necessary for simulating positive flight velocity. The validity of this theory has been established experimentally.

A stagnation, or total, pressure condition results when air is brought to rest without a change in its entropy. Stagnation pressure is essentially the sum of static pressure plus pressure due to velocity (velocity head).

When simulating atmospheric conditions at altitudes above sea level, static air pressure at the engine exhaust generally corresponds to the air pressure at the simulated altitude. If the velocity of the exhaust gases at the engine's exhaust jet-nozzle exit is equal to the speed of sound, it is not necessary to provide the true altitude exhaust-gas pressure.

Since exhaust-gas pressure transmission is at the speed of sound, the exhaust gases upstream from (ahead of) the exhaust jet-nozzle exit cannot "feel" the downstream pressure conditions. With the exhaust gases moving downstream at sonic velocity and the pressure signal trying to travel upstream at the same velocity, the "message" never arrives. This results in a choked jet-nozzle exit condition.

Under a choked jet-nozzle exit condition it is necessary to maintain only the static pressure level at the engine's exhaust low enough to assure that sonic velocity exists at the jet-nozzle exit. The pressure in the test cell's exhaust-gas chamber, thus, can be maintained at a value higher than would otherwise be needed for altitude simulation tests. This is a highly important item in the operation of simulated altitude test facilities. The power requirements of a testing facility increase greatly as the pressure is lowered in the exhaust-gas chamber. Using the choked jet-nozzle exit technique enables the testing range to be

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Reported analyses of simulated tests guide the way to gains in engine performance, endurance

extended without an increase in either power or test equipment requirements.

Under some positive flight velocity test conditions the actual air velocity at an engine's air inlet may require simulation. In supersonic flight an engine's air-inlet diffuser is more closely coupled to the engine than in subsonic flight. The inlet diffuser characteristics, therefore, are more closely coupled to an engine's operating conditions, which means that for tests in which supersonic flight is to be simulated an engine and its air-inlet diffuser are considered as a unit. This makes it necessary to provide actual flight air velocity conditions at the entrance to the engine-inlet diffuser. This may be done by using a free-jet nozzle to direct a jet of air at the engine-inlet diffuser at actual flight conditions of pressure, velocity, and temperature. It also may be done by testing the engine in a supersonic wind tunnel.

Engine Performance and Endurance Developmental Testing

Developmental tests performed on a turbo-jet engine give specific information relating to its performance and endurance characteristics.

Engine performance tests are conducted over a range of simulated flight Mach numbers, altitudes, and attitudes. Tests for engine endurance are conducted over a range of engine speeds and usually include extended tests at sea level static conditions. In some cases endurance tests are run at extreme temperatures or under simulated flight conditions.

Engine performance tests include those involving starting, acceleration, steady state and transient response characteristics, efficiency, windmilling drag, and operational altitude and speed range.

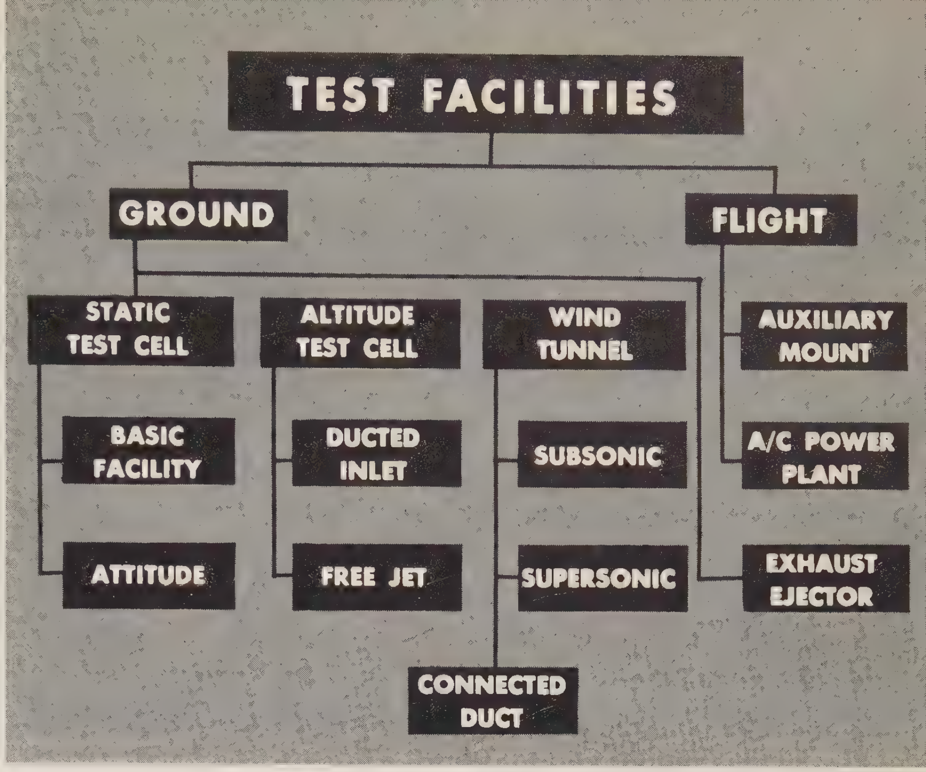


Fig. 1—Developmental testing of a turbo-jet engine to determine its performance and endurance characteristics requires the use of many test facilities. The 3 main facilities for testing an engine on the ground—static test cell, altitude test cell, and wind tunnel—have variations in their setup to permit a wider range of simulated-flight test conditions. After an engine has achieved required performance and endurance characteristics, it is then tested under actual flight conditions. In this case, the engine can be mounted on an auxiliary mount, or it can be used directly as the aircraft's power plant.

Engine performance starting tests consist of starting the engine at various simulated altitudes, or flight speeds, and under extreme temperature conditions. Parameters usually deemed important are time required for starting, time to idle, engine speed at starting, fuel flow at starting, energy required to crank the engine, and energy required for ignition.

Engine performance acceleration tests consist of accelerating the engine from idle to rated speed. Acceleration tests are run at various simulated altitudes, flight speeds, and extreme temperatures. The parameter of major importance for this test is the time required to accelerate. Fuel flow and the engine's dynamic characteristics also are of importance.

An engine's steady state and transient response characteristics are studied by operating it over a range of speeds under environmental conditions resulting from simulated altitudes and flight speeds. (Transient response of an engine is its dynamic response to change in operating conditions—for example, the response of the engine to sudden throttle movement rather than gradual throttle movement.) The parameters studied for this engine performance test include engine thrust, air flow through the engine, energy input to the engine (fuel flow), energy extraction from the engine (power take-off units, or compressed air bleeds), and engine energy conversion (fuel consumption per unit of thrust output).

Efficiency tests are performed on such major engine components as the compressor, turbine, and combustor. Variations in engine performance due to changes in other engine components, such as a modification in air-inlet guide vanes or combustor shape, are studied also.

Windmilling drag is a drag force on a turbo-jet engine when it is not in operation but is rotating due to being in an air stream. Windmilling drag tests are of importance for multi-engine aircraft which may not require the use of all its engines during cruise operation.

Operational altitude and flight-speed performance tests determine an engine's range of altitudes and flight speeds. Such tests are of special importance for military aircraft.

Engine performance and endurance standards are specified by the customer for whom the engine is being developed. Standard military specifications give general outlines for the types of tests to be conducted. The specific engine perform-

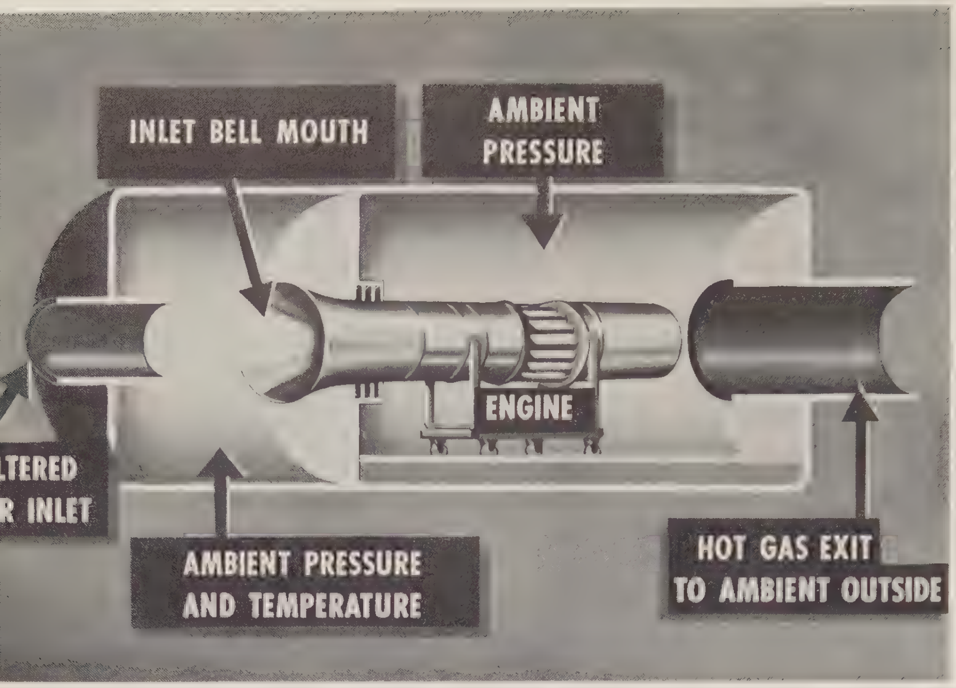


Fig. 2—A static test cell is used for ground developmental tests to simulate conditions encountered by a turbo-jet engine in an aircraft at rest. Filtered air at a controlled temperature and pressure is delivered to the engine through a bell-mouth opening. An exhaust duct removes the engine's exhaust gases and prevents their recirculating back to the engine inlet.

ance and any deviations from standard military specifications are usually included in the engine test specifications.

Engine Developmental Test Facilities

Facilities for engine developmental tests are considered in 2 general areas—ground testing and flight testing (Fig. 1). Ground tests are performed in static test cells, altitude test cells, and wind tunnels. Flight tests are performed with the engine operating either on an auxiliary mount or serving directly as the aircraft's main power plant.

Static Test Cell

A static test cell is used for ground developmental tests at zero flight velocity and is composed of an engine mount, sufficient instrumentation to determine test information, a fuel system, and suitable means to control engine operation. A static test cell also includes a filtered air inlet, a plenum chamber, and duct work to carry away the engine's exhaust gases and prevent the possibility of their recirculating back to the engine inlet (Fig. 2).

Engine thrust is measured by scales or other force-measuring systems, such as strain gages or hydraulic-load capsules. Pressure and temperature pickup probes are provided where needed to determine operating conditions at various locations in the engine. The requisite fuel supply and controls for engine operation also are provided. For safety an engine under test is entirely enclosed by walls; also, sound insulation is provided because of the high noise-level output of turbo-jet engines.

A static test cell for turbo-jet engines can be much simpler in design than the cell shown (Fig. 2). Some installations may include only a concrete base on which an engine support is mounted and to which the required services are provided. The extra expense of building a static test cell as shown, however, usually is justified on the basis of safety and efficiency of operation, protection of the engine from damage which might result from ingestion of rocks or other foreign objects, and improvement in test quality by preventing recirculation of exhaust gases to the engine inlet.

Moving the inlet of a static test cell's exit duct (exhaust duct) close to the engine's exhaust nozzle (jet-nozzle exit) extends the range of test conditions obtainable. The hot, engine exhaust gases act as the primary stream of an ejector, and additional air flow is induced into the test cell's exit duct. Air inlets to the aft portion of the test cell are provided so that this air flow can be obtained. This jet pumping, or ejector, action results in a reduction of the static pressure below the ambient value at the engine inlet in the vicinity of the engine jet-nozzle exit. This combination of ambient air inlet and reduced exhaust pressure conditions permits the simulation of some altitude and flight velocity conditions without the use of air exhaust machinery. A static test cell providing such facilities is known as an *ejectorstatic cell*.

As the exhaust duct is moved closer to the engine's jet-nozzle exit, pressure reduction adjacent to the engine jet-exit varies. In the extreme limit the engine jet-nozzle exit may be coupled directly to the exhaust duct with a frictionless slip joint. For this test condition the engine exhaust serves as the primary stream in an ejector with no secondary flow.

Attitude Test Cell

An attitude test cell, which is a variation of a static test cell, permits an engine to be tested in any desired flight attitude and also allows the attitude of an engine to be varied during a test.

A special attitude test cell (Fig. 3 top) was used in developing turbo-prop engines for the world's first vertical take-off (VTO) aircraft (Fig. 3 bottom). VTO aircraft require engines which can operate for long periods of time in vertical and horizontal positions and also provide reliable operation during transition from the vertical to the horizontal and vice versa. It was through the use of the specially designed attitude test cell that turbo-prop engines providing reliable operation under the various specifications were developed.

Altitude Test Cell

An altitude test cell is used for engine developmental tests in which the altitude range to be simulated is greater than that provided by the ejectorstatic cell. Where positive flight velocity simulation is required, either ducted-inlet or free-jet test cells may be used. The ducted-inlet type of altitude test cell simulates inlet stagnation conditions while the free-jet type of test cell simulates actual airstream velocity conditions.

In the ducted-inlet type of altitude test cell (Fig. 4) air at the requisite temperature and pressure is provided at the inlet-air plenum chamber. The exhaust chamber is evacuated as required for

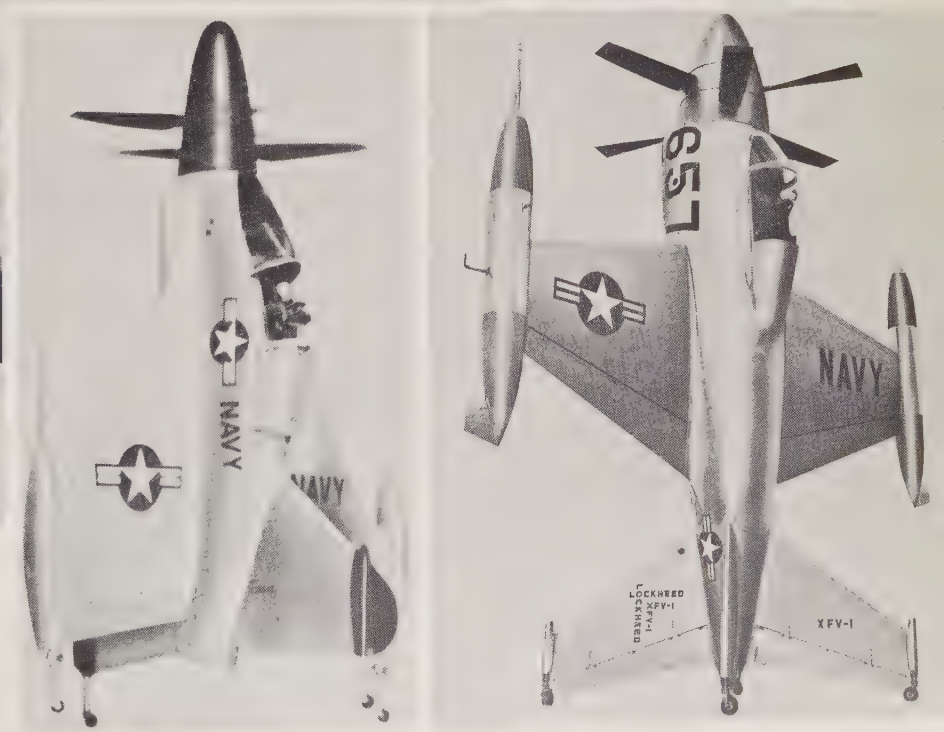


Fig. 3—To investigate the characteristics of an engine in any flight attitude, an attitude test cell is used which permits the angle of the engine's centerline with respect to the horizontal to be varied during a test. Shown here is an attitude test cell (top) used in developing turboprop engines for vertical take-off (VTO) military aircraft.

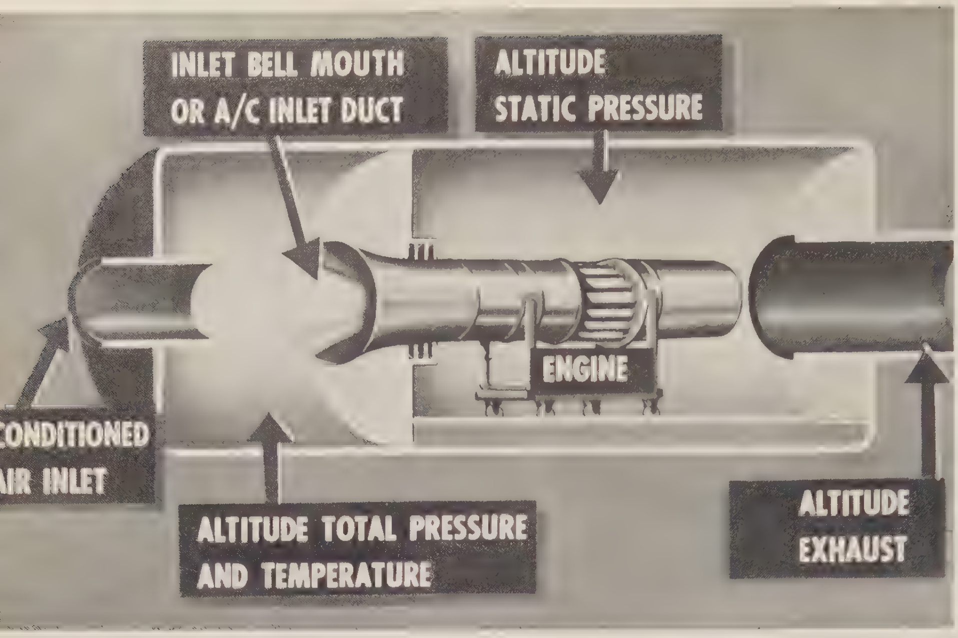


Fig. 4—The ducted-inlet type of altitude test cell is used to simulate positive flight velocity conditions encountered by a turbo-jet engine. In the ducted-inlet setup, air is supplied to the engine at the required temperature and pressure corresponding to a specific altitude. The test cell's exhaust chamber, in turn, is evacuated as required to simulate altitude exhaust conditions. The engine, therefore, is surrounded with atmospheric conditions corresponding to a specific altitude.

altitude exhaust simulation. The engine, therefore, is surrounded with an atmospheric environment at conditions corresponding to the required altitude. The choked-nozzle technique may be used to extend the range of simulated altitudes without increasing power or equipment requirements.

In an altitude test cell setup for a free-jet test (Fig. 5) air is provided to the plenum chamber at the requisite stagnation temperature and pressure and is then expanded through the free-jet nozzle to the desired stream velocity. The stream of air from the free-jet nozzle is directed at the engine-inlet diffuser so that free flight conditions are effectively simulated. For these tests the inlet diffuser is coupled to the engine in the same manner as it would be in the flight vehicle. Performance of the actual configuration of engine-inlet diffuser can then be determined.

With the free-jet test cell setup, engine operation at a specific angle of attack with relation to the air stream also may be studied. The effects of non-symmetrical air flow into the engine due to such operation is very important for an understanding of engine behavior during aircraft maneuvering. Angle-of-attack developmental testing is done by relative misalignment of the free-jet axis and the engine axis. To reduce mechanical complexity it is usually desirable to maintain the engine in a fixed position and vary the position of the free-jet nozzle. In the ultimate setup for this type of altitude test cell the simulated altitude, flight speed, and angle of attack might all be varied. In some cases all of the conditions encountered during an actual flight mission could be simulated.

Wind Tunnel Test Cells

Wind tunnels are needed for tests in which the external aerodynamic characteristics of an engine installation are required. Strictly speaking, tests of external aerodynamic characteristics are part of an engine-nacelle development rather than engine development.

Wind tunnels may be of either the connected-duct or free-stream inlet type. In the test section of a connected-duct type of wind tunnel installation (Fig. 6) a duct is coupled to the engine inlet with a frictionless slip joint. Air at the requisite stagnation conditions is supplied through this duct directly to the engine inlet. The entire engine installation is immersed in the wind tunnel air stream. An exhaust-duct scoop downstream from the engine exhaust intercepts the engine exhaust gases and ducts them from the wind tunnel. The wind tunnel air stream, therefore, is not contaminated by the engine exhaust gases. External aerodynamics of the engine installation may be studied in these tests, and the drag force of the engine can be determined.

To simulate actual flight conditions closely a free-stream inlet type of wind tunnel configuration is used. For such tests the inlet diffuser is coupled to the engine as it would be in the flight vehicle. In some cases all or part of an aircraft may be mounted in the wind tunnel to simulate more closely the actual flight operating conditions.

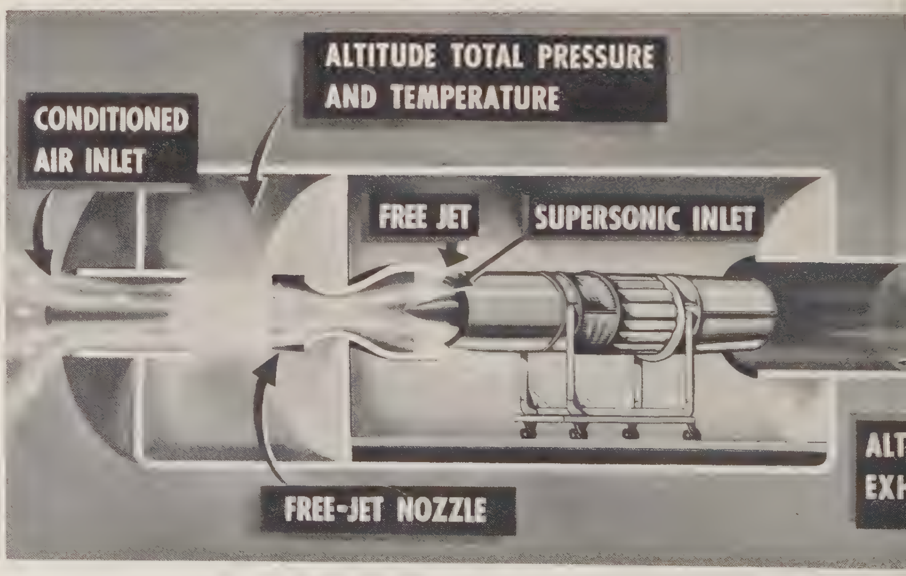


Fig. 5—A free-jet type of altitude test cell is used to simulate actual air-stream velocity conditions. Air, supplied through a conditioned air inlet at the required temperature and pressure, is expanded through the free-jet nozzle to the desired stream velocity. The air leaving the free-jet nozzle is directed against the engine-inlet diffuser which permits effective simulation of free flight conditions. Non-symmetrical air flow to the engine can be simulated effectively by relative misalignment of the free-jet axis and the engine axis.

Flight Testing

In flight testing the engine is operated in an aircraft in flight at the desired test conditions of altitude, velocity, or flight attitude. The engine may be mounted on an auxiliary mount or may be used directly as the aircraft's power plant. As an example of auxiliary mounting, a turbo-prop engine was installed in the nose of a U. S. Air Force B-17 bomber-type aircraft (Fig. 7). During tests the engine furnished part or all of the propulsive power while the aircraft was in flight.

In some instances of engine flight testing for the military, the engines have been positioned on bomb-bay mounts or on supports under aircraft wings, such as bomb shackles. Frequently an engine is flight tested on an auxiliary mount before it is used directly as the aircraft's power plant.

Advantages and Disadvantages of Ground and Flight Testing

The major advantage of ground developmental tests is that test conditions are constantly under the control of test engineers. If re-runs are necessary, it is possible to duplicate approximately the conditions of a particular test. Extensive instrumentation can be used for each type of test since there are no weight limitations. Similarly, any special auxiliary unit requirements, such as loading or power take-off units, can be readily accomplished. Any changes or adjustments needed on test instrumentation or the engine can be made and installed.

Operational maintenance and observation during a test run are more simple for gound testing than for flight testing. Any test conditions which are within the capacity of the test facility to produce may be obtained at any time. If an engine fails or burns, there is no danger to test personnel.

Disadvantages of ground testing include the extensive array of test equipment required to test an engine completely. Ground testing is costly due to the large quantities of power required, facility amortization, and the multiplicity of special test equipment used. A major disadvantage for ground testing is that all flight conditions cannot be simulated exactly—for example, maneuver loads encountered in flight may not be possible to duplicate in ground tests.

Advantages usually cited for flight testing are the simplicity in providing many test conditions at low cost and the ability to apply actual maneuver loads to the engine while it is in operation. Flight testing also provides actual data on engine operation under conditions closer to those encountered in service at the same time that test data are being obtained.

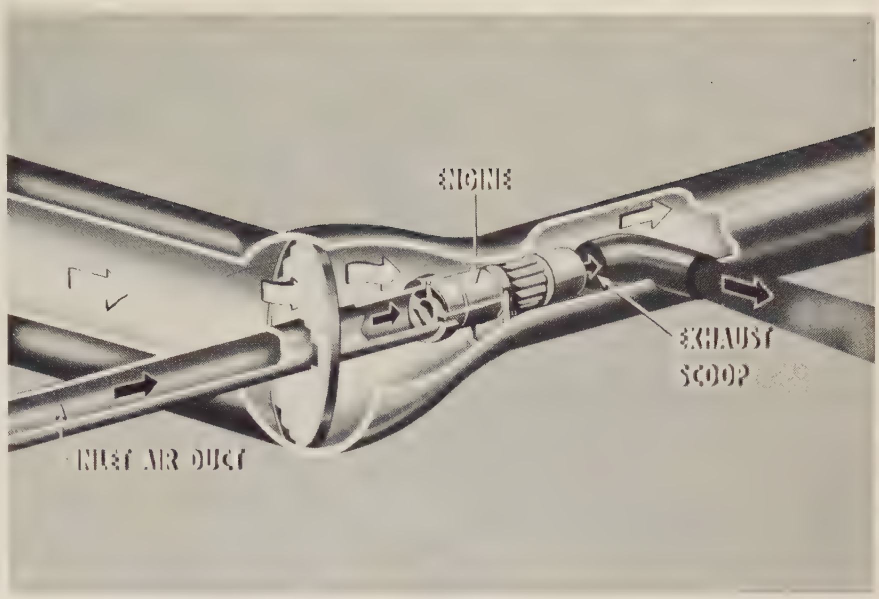


Fig. 6—Wind tunnels are used for conducting tests in which the external aerodynamic characteristics of an engine are to be determined. Shown here is the connected-duct type of wind tunnel. Air at the required temperature and pressure is supplied directly to the engine inlet through an air-inlet duct. This duct is connected to the engine inlet by a frictionless slip joint. An exhaust duct carries away the engine's exhaust gases and prevents their recirculating back to the engine inlet.

The disadvantage of flight testing is the resulting high cost and loss in developmental time if failure occurs in either engine or aircraft. Dollar cost of the test flight vehicle is high, and its useful life may be relatively short. The flight testing time is limited by the comparatively short duration of most flight tests and may be still further restricted by weather conditions. Although the cost of flight testing sometimes may be relatively low, potentially it is always quite high.

Test Data Processing

Test data include all information obtained about an engine's performance and endurance characteristics during a developmental test. The collection and processing of test data are factors of major importance in an engine developmental test program.

Performance characteristics of a test engine may be determined from measurements of force, fluid flow, temperature, pressure, and rotational speed. Certain parameters are used in outlining turbo-jet performance.

To permit comparison of engine performance test data obtained under different test conditions, test data are referred to standard conditions. The standard conditions usually used are sea level static temperature and pressure conditions (519° Rankine and 2,116 lb per sq ft). Occasionally some other set of reference conditions may be used, such as those at some given altitude.

The factors used to correct or refer test data to standard conditions are:

θ = absolute temperature (°R/519)
δ = absolute pressure (psf/2,116).

These factors, in turn, are used in the following performance parameters for turbo-jet engine developmental testing:

$N/\sqrt{\theta}$ = corrected, or referred, engine speed (rpm)

F/δ = corrected, or referred, thrust (lb)

$W_f/F\sqrt{\theta}$ = corrected, or referred, specific fuel consumption (lb per hr per lb of thrust)

$W_f/\delta\sqrt{\theta}$ = corrected, or referred, fuel flow (lb per hr)

T/θ = corrected, or referred, temperature (°R)

$W_a\sqrt{\theta}/\delta$ = corrected, or referred, air flow (lb per sec)

$V/\sqrt{\theta}$ = corrected, or referred, velocity, or air speed (ft per sec or mph)

Fig. 7—When an engine is flight tested, it can be used directly as the aircraft's main power plant or can be mounted on an auxiliary mount. An example of auxiliary mounting in which a turbo-prop engine was mounted in the nose of a B-17 bomber-type aircraft is shown.

where

N = rotational speed (rpm)

F = thrust, or force (lb)

W_f = fuel flow (lb per hr)

T = temperature (°R)

W_a = air flow (lb per sec)

V = velocity, or air speed (fps or mph).

In developmental testing of turbo-prop engines, the parameters also contain terms for horsepower (hp) as follows:

$hp/\delta\sqrt{\theta}$ = corrected, or referred, horsepower

W_f/hp = corrected, or referred, net power specific fuel consumption (lb per hr per hp).

The so-called relative units, such as gauge pressures or °F for temperature, are not generally used in the above performance parameters.

Data Reduction Systems

The processing of information obtained from the basic measurements of force, fluid flow, temperature, pressure, and rotational speed to the corrected engine performance parameters is accomplished in a data reduction system. A typical data reduction system includes information pickups, converters to convert the information into usable form, a storage system to record the data so that they may be rechecked or analyzed at a later date, data reduction or computing, and a means for presenting the data in a meaningful form.

The following typical computation for compressor efficiency is presented as an illustration of a computational method sometimes used. Thermocouples were used for the temperature information pickups, and total (stagnation) pressure probes were used for pressure information pickups. The information reading was manual. The manometer column height was read in inches of absolute mercury. A potentiometer, to which the thermocouples were connected, was used for temperature readings and was calibrated in °F. Temporary and permanent data storage was on data sheets filled in by the test engineers.

Data for only 1 point of compressor efficiency at 1 specific engine speed is used in the example. The following pressures P_1 and P_2 and temperatures T_1 and T_2 each represent the average of several readings taken at the same time and at the same engine speed:

P_1 = compressor inlet pressure = 28.82 in. Hg abs

P_2 = compressor exit pressure = 132.00 in. Hg abs

T_1 = compressor inlet temperature = 66°F = 526°R

T_2 = compressor exit temperature = 430°F = 890°R.

The relationship used for compressor efficiency η_c is

$$\eta_c = \frac{\text{ideal temperature rise across compression}}{\text{actual temperature rise across compression}}$$

$$\eta_c = \frac{(P_2/P_1)^{\frac{K-1}{K}} - 1}{(T_2/T_1) - 1}$$

where

η_c = compressor efficiency (per cent)

K = ratio of specific heats for air at constant pressure and constant volume. For the specific temperature range of air in the example, $K = 1.4$.

Therefore

$$\eta_c = \frac{(132.00/28.82)^{0.286} - 1}{(890/526) - 1}$$

$$\eta_c = 78.8 \text{ per cent.}$$

In the example the temperatures were converted to absolute units (°R) before being used in the equation for compressor efficiency.

A more modern method used for processing information from raw test data to corrected engine performance paramaters is the automatic data reduction system where the desired engine operating condition is first established. The system is then put into operation, and the information is picked up, processed, and final results automatically tabulated or plotted.

The salient features of a simple, automatic data reduction system (Fig. 8) include both digital and analog inputs,

a converter to digitize the analog data for the digital computer, storage capacity which is required during the data reduction process, raw data storage for the purpose of records, an arithmetic unit, program control and calculator, intermediate output registers, digital to analog converters if required for curve plotting, and automatic printers or typewriters to tabulate the data desired in tabular form.

Raw test data output obtained from the information pickups may be used in either digital or analog form depending on the measuring devices used. An example of digital output is a revolution counter whose output is numerical. An example of analog output is a voltage as in the output from a strain gauge. It is frequently simpler to obtain a higher degree of computational accuracy with digital computers than with analog equipment. In view of this digital computers are used where necessary, and the analog data are digitized before being fed to the digital computer. Data storage is required to hold the data while being processed, as well as for future reference.

The computing system includes whatever means may be necessary to transform the incoming raw test data from the information pickups to the desired end result. Also, means are provided to convert the data from the form most convenient for processing to the form most convenient for the user of the data. In some cases these forms may be quite different.

Test Data Analysis and Engineering Report

The final step in the turbo-jet engine developmental test program involves careful analysis of the test data. The data are plotted, cross plotted, and studied until as much as possible is learned about the engine's performance. Data from one test are correlated with data from other similar tests and comparisons made. Frequently this data analysis points to the need for further tests to obtain desired performance information.

In the evaluation of data from a developmental test it is quite important to consider experimental inaccuracies and errors introduced in all phases of the test. It is frequently necessary to conduct a large number of tests to evaluate adequately small design changes in engine components.

After each developmental test has been completed and a thorough analysis made of all test data, the knowledge gained is transmitted to all groups concerned by means of the engineering report. Inasmuch as the report is all that most people will ever see of the developmental testing effort, its importance cannot be overemphasized. In the final consideration, the developmental test is only as valuable as the information obtained, and this information must be disseminated by means of a clear, concise, complete, and readable engineering report.

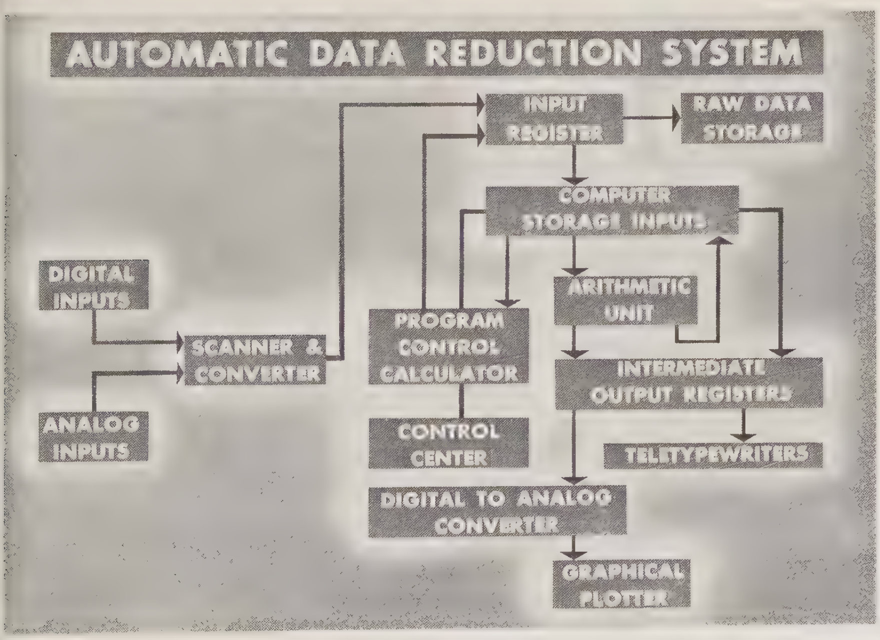


Fig. 8—The processing of raw test data to corrected engine performance parameters is accomplished in a data reduction system. Shown here is an outline of the operational sequence of a simple data reduction system of the automatic type. When using this type of data reduction system, the desired engine operating condition is established first. The system then is put into operation, and the information is picked up, processed, and final results automatically tabulated or plotted.

Summary

The turbo-jet aircraft engine developmental testing program at Allison Division is based on obtaining complete and concise information on an engine's performance and endurance characteristics. The engine is first subjected to a series of ground developmental tests which simulate conditions encountered by the engine in an aircraft at rest and in flight. After the engine meets pre-flight requirements, it is then subjected to actual flight tests.

Ground developmental tests are performed in static test cells, altitude test cells, and wind tunnels. Flight developmental tests are performed with the engine operating on either an auxiliary mount or directly as the aircraft's main power plant.

Data collected during a developmental test is processed from raw test data to corrected engine performance parameters in an automatic data reduction system. The data are then analyzed, and frequently this analysis indicates the need for further tests to obtain desired engine performance information.

The final step in a developmental testing program is the preparation and writing of the engineering report. The information gained from the testing program becomes of lasting value only when it is communicated to everyone concerned in a clearly written and accurate report.

The present facilities at Allison Division encompass static tests, altitude tests, component environmental testing, and flight tests. Future test facilities will greatly extend the types of developmental testing which may be conducted and will broaden the range of test conditions over which tests are conducted.

The GENERAL MOTORS ENGINEERING JOURNAL is now published quarterly instead of bi-monthly as formerly. An index of the 5 issues in Volume 3 is included in this final issue for 1956. Educators who desire copies of papers published previously in the JOURNAL may obtain extra copies of the appropriate issue upon request to the editor. Comments are invited at any time.

Weight Control: a Vital Factor in Body Engineering

By EDWARD R. FITZPATRIC
and FRANCIS A. WICKERT
Fisher Body Division

Weight control is important in body engineering because weight is a function of cost, economy of operation, and ride and handling characteristics of an automobile. Through deft design, Fisher Body Division engineers keep the weight of the body structure to a minimum consistent with size and high standards of quality and structural strength. Working with clay models, detail drawings, and, ultimately, production parts, engineers collect detailed weight information on each body part. With the aid of automatic data processing equipment they maintain continuous control over the weight of such parts, as well as the weight of the complete body assembly.

Engineers keep automobile bodies on a constant diet; the result, more value for the customer

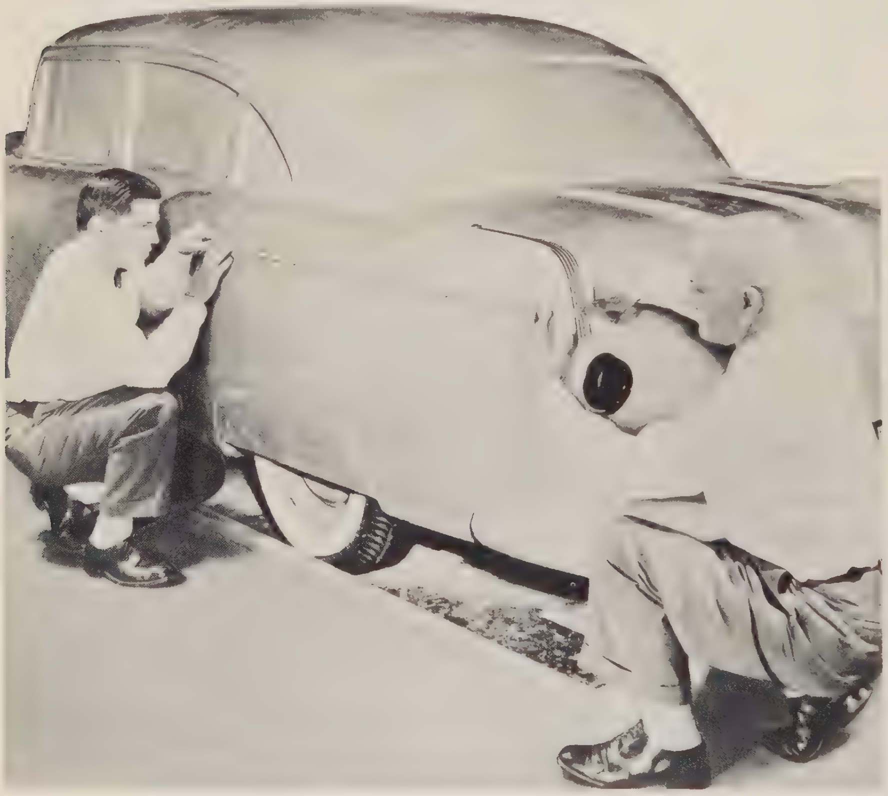


Fig. 1—Clay model surfaces are scaled and developed into a plane, and, by comparing areas to a former model, an accurate weight estimate of the body exterior is obtained.

THE task of the automobile body engineer is to reproduce in metal the body fashions created by the stylist. Working from full-size clay models and layout drawings developed by the General Motors Styling Staff, Fisher Body engineers design and develop all of the necessary construction and detailed information to produce a sound, functional, and attractive car body in accordance with mass production methods. Many factors are taken into account, such as materials, manufacturing processes, structural strength, and overall weight of the body assembly. This discussion deals with the factors of weight and structural strength, which necessarily go hand-in-hand.

Weight Control of Automobile Bodies Taxes Engineering Ingenuity

Weight control is a particularly vital factor in body engineering because the results show up in the form of more value to the customer. Public demand is responsible for the larger, roomie automobiles being produced today, an without a vigorous weight control pro gram these larger cars would necessaril require more metal which, in turn, woul make them appreciably heavier an costlier than previous models. Mor material means higher manufacturin costs, which would have to be passe along to the customer in the form o increased car prices. The objectives of weight control program are, therefor 3-fold: first, to reduce the weight of th body structure; second, to minimize an weight increases if weight reductions ar not possible without sacrificing structura strength and rigidity; and third, t reduce manufacturing costs through th application of engineering ingenuity i the design of body components.

While weight control in automobil bodies is aimed primarily at saving ma terial, there are other advantages. An reduction of weight in the body structur could lower the center of gravity of th car and, thus, increase road-holdin ability. Weight reductions also could b reflected in better fuel economy.

Weight Control Begins at the Clay-Model Stage and Continues Through to Production

The weight of a particular body styl is controlled continuously from the clay model stage right through to the tim the body is put into production. Contro includes estimating the weight of the cla model, calculating the weight of release parts, and weighing and recording th weight of the actual parts as they ar made.

Generally, clay model weight esti mates are made by assuming that th structure and the mechanical hardwar are similar to the previous model excep

Fig. 2—As the design features of the clay model are translated into experimental or production drawings, the weight of each part is calculated. Generally, detail drawings are used, but occasionally engineers must work from layout or assembly drawings. The planimeter is used to measure areas and the map measure to obtain the length of curved surfaces.

in cases where design features definitely indicate different structural requirements (Fig. 1). All major parts of the body, such as exterior sheet metal panels and glass areas, are compared to the previous design and weights adjusted accordingly. For example, if the roof panel on the clay model is essentially the same shape as in a 60 in. by 80 in. roof panel of a previous model, except that it is approximately 3 in. longer, the increased metal on the proposed panel would be 180 sq in. Assuming 0.035-in. thick steel weighing approximately 1 lb per 100 sq in. is used, the estimated weight increase would be close to 1¾ lb.

It is interesting to note that in computing the weight of glass areas a unit area of glass ¼-in. thick weighs about twice as much as the steel it displaces. For example, if the glass height of the windshield is raised 2 in. for a width of 60 in., the increased glass area on the proposed windshield amounts to 120 sq in., or 2½ lb. The net increase in body weight, therefore, would be one half that amount, or 1¼ lb.

As the body design features of the clay model are translated into experimental or production drawings, the weight of each part is calculated. Detail drawings are generally used, but occasionally it is necessary to work from a layout or assembly drawing. The planimeter is used to determine surface areas and the map measure to obtain the length of curved surfaces (Fig. 2).

The weights of sheet metal parts are usually calculated by developing the parts into a plane and then measuring the actual area. Where compound curved

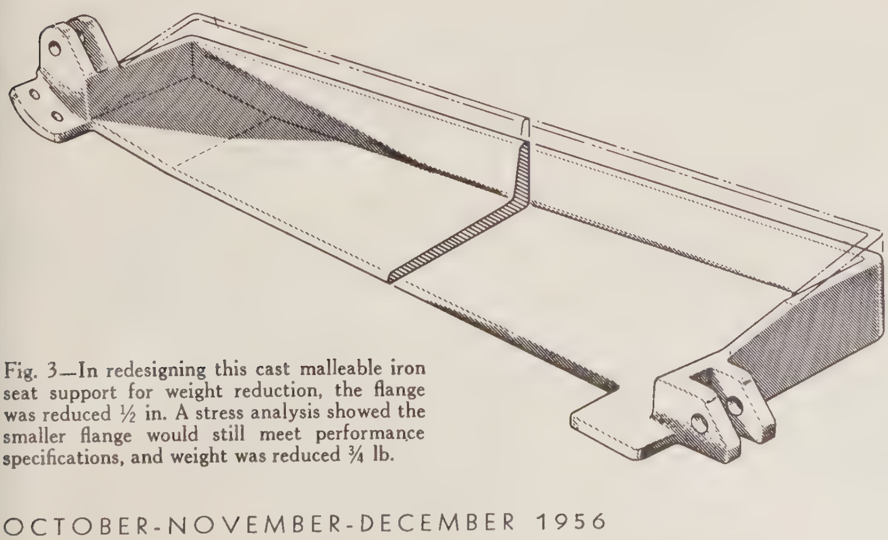


Fig. 3—In redesigning this cast malleable iron seat support for weight reduction, the flange was reduced ½ in. A stress analysis showed the smaller flange would still meet performance specifications, and weight was reduced ¾ lb.

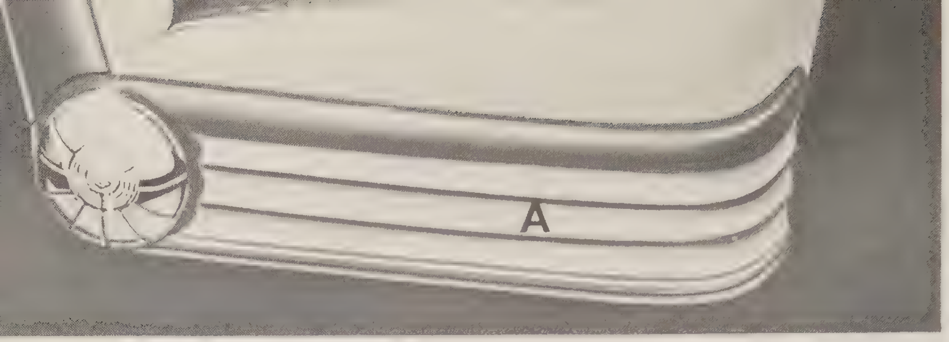


Fig. 4—While aluminum costs 8 times as much per pound as steel, there are certain places in the body assembly where it functions efficiently and effectively as a substitute for steel. A typical example is the front seat side panel *A*.

surfaces and other irregular shapes, as well as areas where the metal is drawn, are involved, the problem of determining surface area is much more complex. Vellum overlays are made with superimposed views indicating the plus and minus differences between similar parts. Experience in making allowances for draw in stamped parts is helpful in such cases.

In calculating the weights of solids, such as castings and plastic and rubber parts, volume often is determined by breaking the part down into the more simple geometric shapes and calculating the volume of each.

Calculated weights are considered estimates and are eventually superseded by the actual weights of handmade parts for experimental models. As production parts become available, they replace all other weights.

Use of Reinforcing Beads, Ribs, and Lightening Holes Minimize Metal Requirements

Two ways of minimizing steel requirements in an automobile body structure are: (a) the use of reinforcing beads and ribs to strengthen stampings instead of increasing metal thickness, and (b) the use of lightening holes when other parts can be fabricated from the scrap metal produced in the stamping operation.

Some time ago a weight study was made of a newly designed deck lid. This study revealed that the new design weighed 4 lb more than the design it was to replace. By reducing the size of the reinforcing members at the hinges and by enlarging the lightening holes in the inner panel, the new lid was held to the same weight as the previous design without sacrificing structural strength in any way.

Weight-Conscious Engineers Eye Castings, Too

Another typical example of weight saving involved a seat support. The support, a malleable iron casting, was designed originally with a 1¾-in. flange (Fig. 3). A stress analysis of the part indicated that the flange could be reduced ½ in. and still meet performance specifications. Total seat weight was reduced ¾ lb. While this may seem insignificant, close attention to any possibilities for weight reduction can pare many pounds from an automobile body assembly.

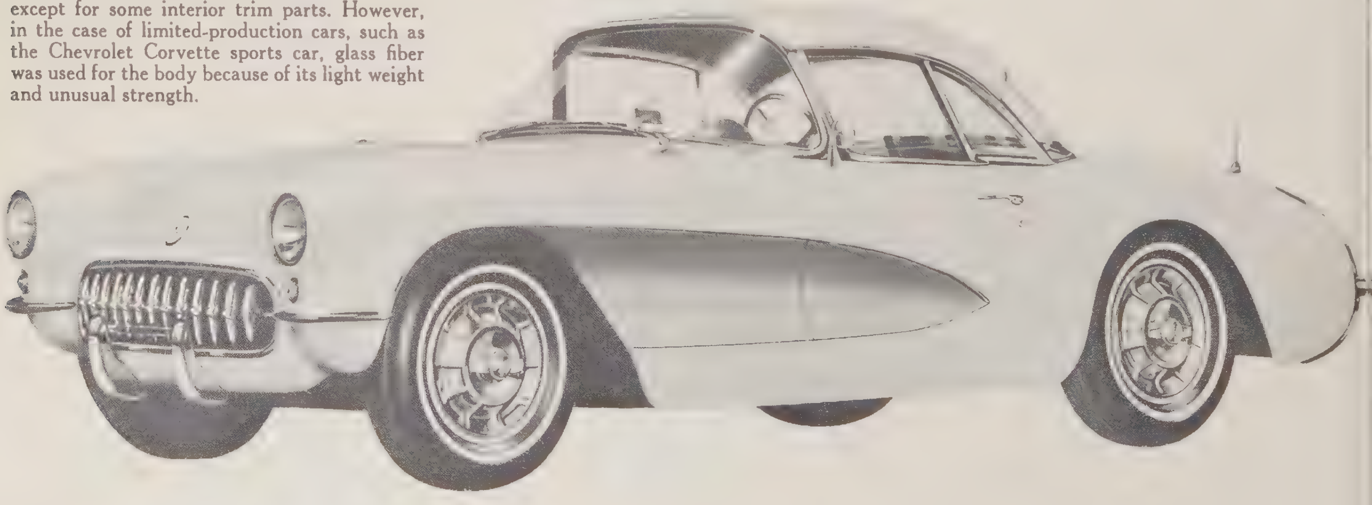
Plastics and Lightweight Metals Offer Possibilities for Weight Reduction

The increased availability of lightweight materials, such as plastics and aluminum, offer additional possibilities for making substantial weight reductions in automobile bodies. Possible applications for aluminum would be in door panels and deck lids as its lightness would permit easier opening and closing. Studies and experiments with aluminum over the past 30 years, however, indicate that its cost prohibits any wide use in automobile body structures.

While aluminum weighs only ⅓ as much as steel, thicker sections must be used for comparable structual quality. Thus, the net savings in weight would be about ½ the weight of the steel part. In a 48-lb steel deck lid, for example, the saving would be approximately 24 lb. Since aluminum costs 8 times as much per pound as steel, the added cost would be 4 times that of steel. Furthermore, aluminum is more difficult to weld or solder and dents much easier than steel. There are, however, places in the body where aluminum is serving effectively and efficiently as a substitute for steel (Fig. 4).

Like aluminum, plastics have not found wide use in high-volume production automobile bodies except for some interior trim parts. However, in the case of limited-production cars, such as the Chevrolet Corvette sports car, glass fiber was used for the body structure because of its light weight and unusual strength (Fig. 5).

Fig. 5—Plastics have not found wide use in high-volume production automobile bodies except for some interior trim parts. However, in the case of limited-production cars, such as the Chevrolet Corvette sports car, glass fiber was used for the body because of its light weight and unusual strength.



Stress Analysis Aids Weight Control of Automobile Body Structures

As pointed out previously, weight control and structural strength are inseparable factors in automobile body design; each must be considered in the light of the other. In the past the common solution to structural rigidity problems was to increase the gauge of the material which made the part strong enough but at the same time added weight. In recent years much progress has been made in the field of experimental stress analysis, and new techniques allow a completely fresh approach to the design of automobile bodies in making them safer, lighter, and more economical to build.

Until recently the strength of an automobile body structure was predicated on assuming values for torsional stiffness which would insure satisfactory ride and handling characteristics. Little was known about the magnitude and direction of external loads on each body member under critical load conditions. Experimental stress analyses of such parts have paved the way for new structural designs which, in many cases, have permitted substantial weight reductions.

Strain gauges and brittle lacquer have been useful tools in making experimental stress analyses. Beaming devices, twist, and bump-roll machines have served to evaluate the stiffness of body structures. Such machines can apply many types of loads to the body structure through supporting chassis frame members.

The question frequently arises as to whether future automobiles will have to maintain the same bending and torsional stiffness characteristics as present-day models. It is quite possible that future developments in suspension systems and body assemblies will be of such a nature that structural strength rather than torsional stiffness will become the governing factor in design criteria.

Automatic Data Processing Speeds Up Weight Control Program

A punch card system is used by Fisher Body engineers to compile weight data quickly, simply, and effectively. There is a separate card for each body part on which is key punched such information as the part number, part name, *UPC* (*UPC* is a standard system for classifying automobile body parts according to function and economic importance), model year, body style, quantity, gauge, weight,

CENTER PILLAR CONSTRUCTION

PART NUMBER	PART NAME	STYLE	UPC	YEAR	SO	GAGE	QTY	1954 WEIGHT	ST	1955 WEIGHT	ST
4627770	PANEL CTR PLR OTR RT	1069W	D 01	54	M	059	01	5 500	A		
4639808	PANEL CTR PLR OTR RT	1019	D 01	55	M	067	01			5 826	A
4627771	PANEL CTR PLR OTR LT	1069W	D 01	54	M	059	01	5 500	A		
4639809	PANEL CTR PLR OTR LT	1019	D 01	55	M	067	01			5 826	A
4643339	PANEL CTR PLR INR RT	1069W	D 01	54	M	047	01	2 062	A		
4639815	PANEL CTR PLR INR RT	1019	D 01	55	M	047	01			1 937	A
4643340	PANEL CTR PLR INR LT	1069W	D 01	54	M	047	01	2 062	A		
4639816	PANEL CTR PLR INR. LT	1019	D 01	55	M	047	01			1 937	A
4594780	REINF PILLAR OUTER	1069W	D 01	54	M	067	01	4 125	A		
4639812	REINF PILLAR OUTER	1019	D 01	55	M	075	01			5 013	A
4594781	REINF PILLAR OUTER	1069W	D 01	54	M	067	01	4 125	A		
4639813	REINF PILLAR OUTER	1019	D 01	55	M	075	01			5 013	A
4595553	STRIP PROTECTOR RT	1069W	D 01	54	M	035	01	656	A		
4667528	STRIP PROTECTOR RT	1019	D 01	55	M	[illegible]	[illegible]			821	E
4595554	STRIP PROTECTOR LT	1069W	D 01	[illegible]	[illegible]	[illegible]	[illegible]	656	A		
4667529	STRIP PROTECTOR LT	1019	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			821	E
4599451	FILLER CTR [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	118	A		
4643469	FILLER C[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			054	A
4601510	FILLER C[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	090	E		
4667526	FILLER C[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			113	A
4601511	FILLER C[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]90	E		
4667527	FILLER C[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			113	E
4646341	BOLT CLIP[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			040	A
4629829	WASHER B[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			008	A
4629828	NUT BOLT [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			010	A
								[illegible]84		27 532	
4609346	RETNR CTR[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]3	A		
4609347	RETNR CT[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	A		
4651957	IDTN CENT[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			780	A
TO MATCH	CLOTH ME[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]88	E		
TO MATCH	CLOTH ME[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			081	E
TO MATCH	LEATHER [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]42	E		
TO MATCH	LEATHER IM[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			819	E
806X32	WADDING BLUE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	103	A		
806X32	WADDING BLUE	101[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			042	E
4558951	FASTENER	1069W	D 06	[illegible]	[illegible]	[illegible]	[illegible]	032	A		
4649733	FASTENER CTR PLR FND	1019	D 06	55	P	[illegible]	[illegible]			070	A
4559658	NAIL	1069W	D 06	54	P		1[illegible]	048	A		
4559658	NAIL	1019	D 06	55	P		16			048	A
4629746	STICK TRIM CPL FT RR	1069W	D 06	54	P		04	080	A		
1428X	TAPE	1069W	D 06	54	Z			002	E		
104879	TACK	1019	D 06	55	P					003	E
FS-607	CEMENT	1019	D 06	55	P					047	E
								3 221		1 200	
4628803	MOLDING REV CTR PLR	1069W	D 08	54	T		02	060	A		
120622	NUT	1069W	D 08	54	P		02	002	A		
178369	WASHER	1069W	D 08	54	P		02	004	E		
								066			
	TOTAL							28 871		28 732	

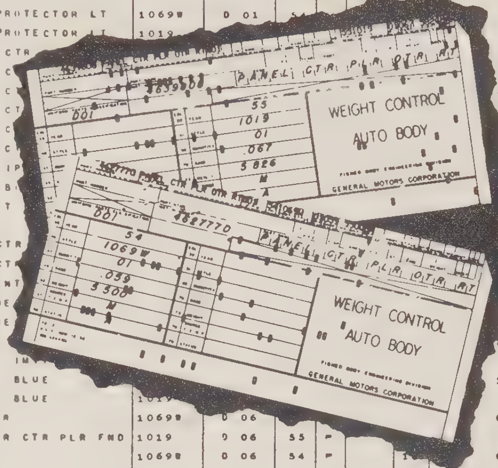


Fig. 6—Weight control data are assembled on key punched cards and tabulated using automatic data processing equipment. Such equipment will automatically accumulate and print simultaneously the weight of each part, the total weight of major body components, and the total weight of the whole body assembly.

source (purchased or made), and status (actual weight or estimated). Also, each card is coded to identify the particular part with some major body component, such as the underbody, front end, or roof.

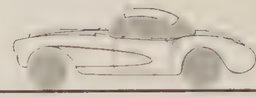
Information on the punched cards can be transcribed quickly and accurately by automatic data processing equipment into tabulated report form. Such equipment will accumulate and print simultaneously the weight of each part, the total weight of each major body component, and the total weight of the whole body assembly.

Consolidated reports which compare the weights of typical body parts from one model year to another are frequently used. These, too, are processed on automatic sorting and tabulating equipment (Fig. 6). The consolidated report shows at a glance any variances in weight and is extremely advantageous in controlling the weight of the various body sections.

Summary

While the total weight of the average automobile body has increased approximately 350 lb during the past 25 years, its size has increased in greater proportion. Thus, the principal objective of a weight control program is to minimize weight consistent with size, quality, and structural strength in a changing product. Indeed, weight control of automobile bodies is a behind-the-scenes factor which plays an important part in building more value into today's automobiles.

Engineers Set Serviceability Standards for Reinforced Plastic Automobile Bodies



By JOHN G. COFFIN
Chevrolet Motor Division

Lightweight, glass reinforced plastic car bodies— a new automotive trend

Although the plastic industry is relatively new, it has grown tremendously in the last decade. Always in search of better, more economical ways to do things, Chevrolet Motor Division engineers explored the plastics field for a material suitable for car bodies. Extensive research, development, and testing resulted in the Chevrolet Corvette, a plastic-bodied sports car—the first of its kind manufactured on a production basis. Problems which arose in relation to the use of reinforced plastic for the Corvette body have been resolved, and the inherent advantages reinforced plastic offers indicate that this is a worthwhile field for continued endeavor.

Recently, great progress has been made in the development and application of plastic materials in industry and manufacturing. The possibility of using plastics for automotive bodies has been of much interest to the plastics industry and has greatly stimulated developmental work in this connection. Chevrolet's Corvette sports car marks the first use of plastic for major automobile body components on a production basis (Fig. 1). The body shell, which weighs 340 lb, is comprised of reinforced plastic panels consisting of approximately 40 per cent glass fiber, 45 per cent polyester synthetic resin, and 15 per cent mineral filler.

Before production, stress calculations were made and tests conducted on typical glass fiber reinforced plastic materials to determine the requirements of the Corvette body and the limitations of available materials. Specifications were established to insure procurement of production material of suitable quality. After a considerable number of plastic-bodied cars had accumulated substantial mileage and time in service, it was found that several factors relative to body material composition and characteristics were of more than ordinary importance. The aspects of special interest in that they affect durability generally and appearance particularly after lengthy service are

- Weathering resistance
- Impact resistance—balanced with strength and rigidity
- Bonding—problems of joining major panels and the design of bonded joints

The service-encountered deficiencies of a reinforced plastic body in any of these categories usually show up as appearance defects, notably glass fiber pattern, surface cracking, surface waviness, and exterior cracking of bonded joints.

Before discussing the details of consequence in the foregoing areas from a serviceability standpoint, it might be worthwhile to consider the strength of this new body material compared with

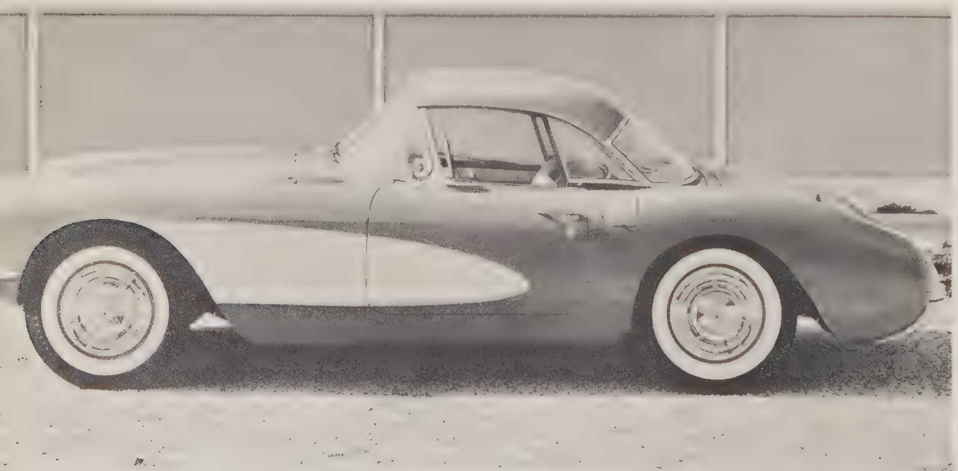


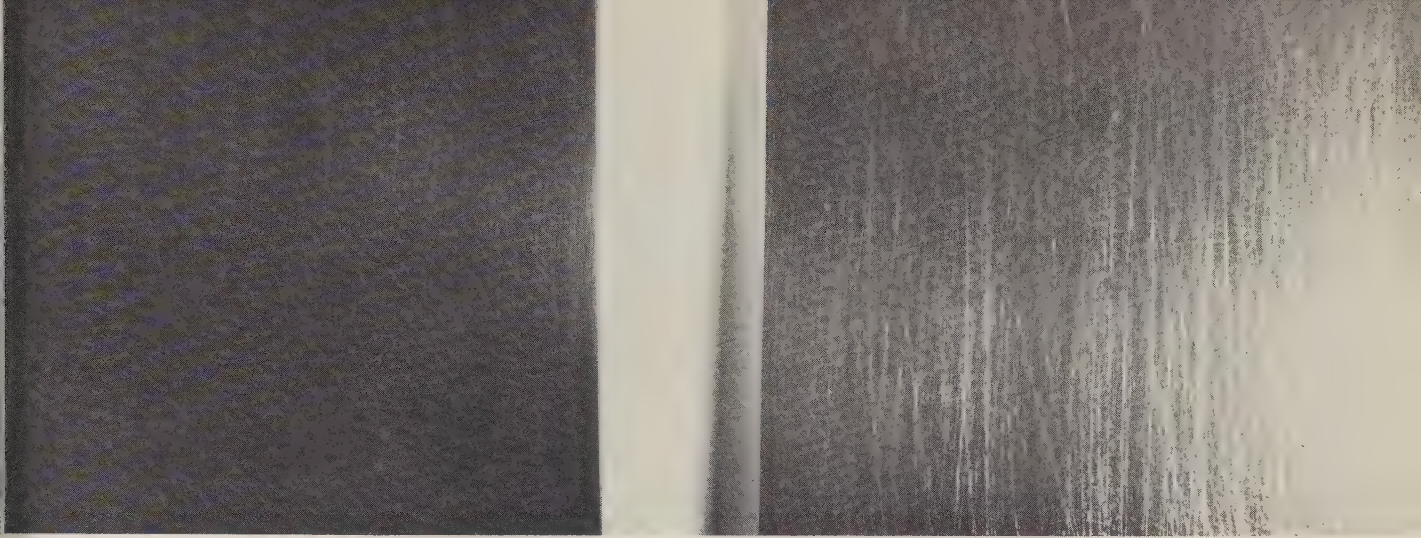
Fig. 1—The Chevrolet Corvette sports car marked the first use of reinforced plastic for major automobile body components on a production basis. The 340-lb body shell is comprised of reinforced plastic panels consisting of approximately 40 per cent glass fiber, 45 per cent polyester resin, and 15 per cent mineral filler.

STIFFNESS IN TENSION = MODULUS X THICKNESS X / LOAD X LENGTH

STIFFNESS IN BENDING = MODULUS X THICKNESS³ X / LOAD X LENGTH

	THICKNESS (in.)	FLE MO (
STEEL	0.036	30,0
PLASTIC	0.100	1,3

Fig. 2—Since thickness is a cube factor in bending, this results in almost equivalent flexural stiffness between steel and plastic for those thicknesses of material commonly used (0.036 in. for steel and 0.100 in. for plastic). This is not true for tensile rigidity. However, this deficiency is of no consequence under dynamic load conditions, but the larger static deflections must be allowed for in assembly operations.



that of more familiar materials of construction.

Greater Thickness Provides Sufficient Strength and Rigidity

In terms of strength (psi), steel is between 2 and 3 times stronger than plastic; however, plastic panels nominally 1/10 in. thick are used compared with the commonly used 0.036 in. (20 gauge) steel. The plastic part is, thereby, actually stronger than a corresponding steel part (Table I).

This greater thickness assures adequate stiffness, as well as ample tensile, flexural, and impact strengths. With regard to flexural rigidity, the plastic modulus is only about 1.3×10^6 against 30.0×10^6 for steel. In bending, the thickness is a cube factor (Fig. 2) and this results in almost equivalent flexural stiffness between steel and plastic in these thicknesses. Tensile rigidity, however, is increased by the first power of thickness, and the greater thickness does not come close to nullifying the modulus deficiency. The magnitude of this would be expected to cause noticeably high deflection of load-bearing members of box section design, hinge pillars for example, where tensile modulus must be considered. However, this lack of tensile rigidity proves harmless to the vehicle under dynamic load application conditions and can be ignored provided the larger static deflections are allowed for in assembly.

Control of Plastic Composition Will Alleviate Fiber Pattern in Weathering

While impervious to corrosion (in the usual sense) in practically any environment, the surface appearance of some reinforced plastic compositions is adversely affected by exposure to high

Fig. 3—After painting, the roughness of "as molded" panels is obscured as the paint fills in the depressions (left). The appearance of fiber pattern, or fiber trace (right), is caused by high humidity conditions and to some extent by differential paint film thickness.

atmospheric humidity and elevated temperatures.

The appearance of glass fiber pattern, or fiber trace, under high humidity conditions (Fig. 3 right) is partially due to differential paint film thickness. In a typical, unpainted reinforced plastic molding, the surface roughness is caused by resin shrinkage, and the fibers are in relief over hollows in the resin-rich "matrix." After painting, this roughness is obscured as the paint fills in the depressions (Fig. 3 left). On subsequent exposure to moisture, however, the paint film absorbs water and swells in proportion to its original thickness. Consequently, the greater thickness of paint over resin-rich areas becomes raised above that covering the fibers, and the "fiber map" becomes noticeable. Actually, then, this fiber pattern is visible in reverse; that is, the surface over the glass fibers is depressed and that over resin-rich areas is raised.

Some of the fiber pattern which becomes prominent with absorption of moisture is a function of the water resistance and polarity of the resin used in making the plastic panels. In order to keep the influence of the resin on fiber pattern at a minimum, 0.5 per cent maximum water absorption after 24-hr immersion of uncoated plastic parts in water at room temperature is specified.

The appearance of fiber pattern due to

TYPICAL PHYSICAL PROPERTIES

PROPERTY	REINFORCED PLASTIC	STEEL (AISI C-1010)
Specific Gravity	1.50	7.87
Thermal Expansion (coefficient per °F)	12×10^{-6}	6×10^{-6}
Thermal Conductivity (Btu per hr per sq ft per °F per in.)	2	310
Specific Heat (Btu per lb per °F)	0.3	0.1
Water Absorption (per cent weight increase after 24 hr)	0.5	—
Corrosion (5 per cent salt spray)	not affected	rusts
Flammability	burns slowly	—
Tensile Strength	17,000 psi	45,000 psi
Yield Strength	17,000 psi	35,000 psi
Flexural Strength	25,000 psi	—
Flexural Modulus:		
at room temperature	1,300,000 psi	30,000,000 psi
at 180° F	600,000 psi	30,000,000 psi
Impact Cracking Resistance:		
at room temperature	10 in.	6 in.
at −10° F	6 in.	6 in.
at room temperature after aging 7 days at 212° F	8 in.	—
Impact Strength notched Izod	15 to 20 ft-lb per in.	—
Hardness	Rockwell M-100	Rockwell B-80
Wet Strength Retention (per cent original strength retained after 2 hr in boiling water)	70 per cent	—

Table I— In terms of strength (psi), steel is between 2 and 3 times stronger than plastic. However, plastic panels nominally 1/10-in. thick are used compared with commonly used 0.036 in. (20 gauge) steel. Thus, a plastic part is actually stronger than a corresponding part made of steel.

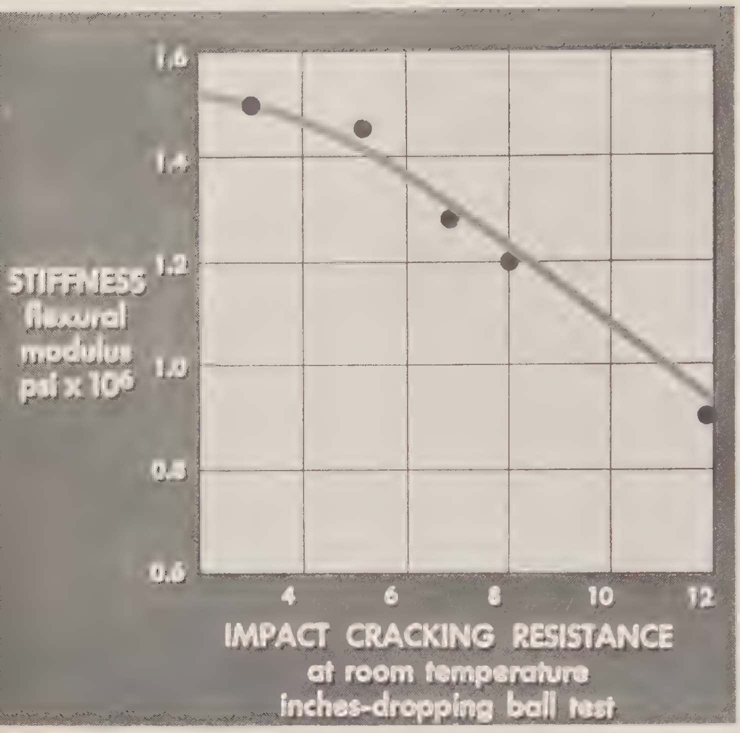


Fig. 4—The above curve shows the relationship between stiffness and impact cracking resistance of reinforced polyester resin. These data were determined by dropping a 1½-lb steel ball through distances varying from 4 in. to 12 in. onto a 1/10-in. thick resin panel supported in a 5-in. diameter frame.

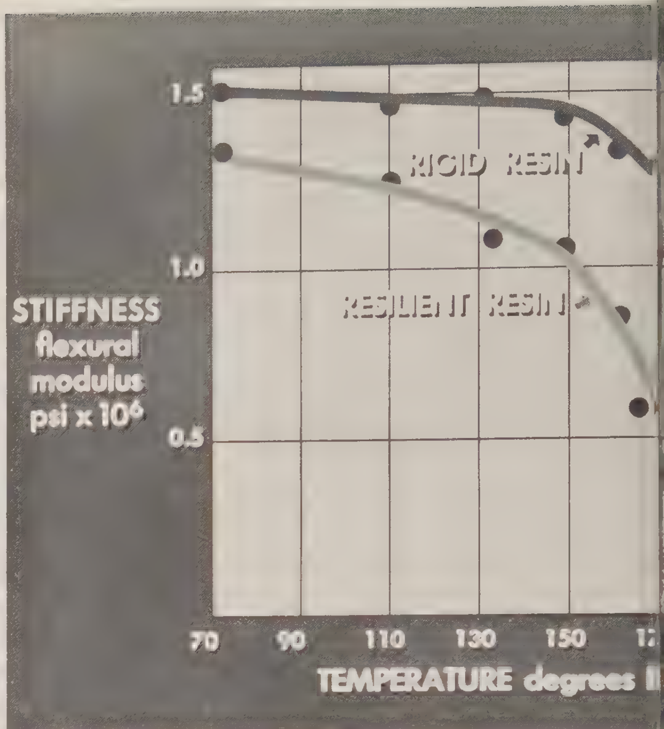


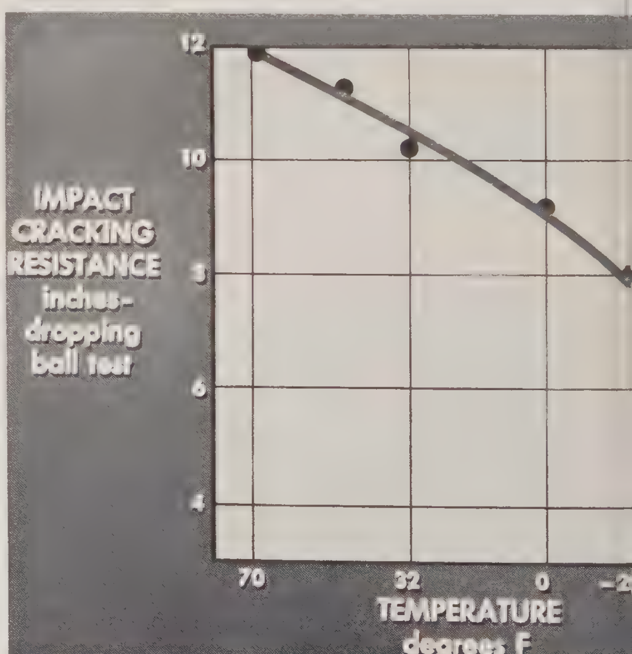
Fig. 5—The stiffness of reinforced polyester resin decreases with increases in temperature. However, because reinforced plastic has superior properties in damping out the duration of vibration periods, no objectionable degree of flexibility has been observed.

exposure to elevated temperature may be permanent or temporary. If the resin in a laminate is undercured, permanent shrinkage occurs on heating. The resultant fiber pattern can be removed by polishing the overlaying paint film. Fiber pattern caused by undercuring can be averted through proper curing and hardness control by the plastic molder. Tests of strength and modulus also will evidence improperly cured resin. Temporary fiber appearance can be noticed on heating of fully cured painted panels to about 180° F or higher (180° F is the maximum anticipated service temperature). These temperatures cause the glass-rich and resin-rich portions to expand differentially. When the material cools, the pattern disappears. Fiber pattern attributable to this phenomenon is, therefore, of little practical concern.

Optimum Balance Between Resilience and Rigidity Is Necessary for Satisfactory Fatigue Life, Impact Resistance, and Stability

Originally, it was found that reinforced polyester laminates having a resin-rich surface (gel-coat) of poor flexibility (low cured elongation) were susceptible to cracking if used for body panels subject to localized impact loads or high and repeated flexing stresses. For example, stones thrown by the car's tires would cause "stone bruising," or star-like cracks, on the outer surfaces of panels which were impacted on the underside.

Fig. 6—The modulus of reinforced polyester resin decreases with increases in temperature. Very low temperatures cause the material to become brittle, thereby offering less impact resistance. Specifications for impact resistance must be high enough to insure against cracking at any temperature likely to be encountered in service.



A reverse impact, or falling ball impact test was developed to evaluate resistance to this type of damage. Early experimental bodies having rigid resin gel-coat developed numerous failures of this type in service on gravel roads.

As service background was accumu-

lated it was found that die-molded, reinforced plastic panels without gel-coat have superior resistance to impact and flex cracking in service in comparison with similar gel-coated, hand lay-up or bag-molded panels of equivalent impact cracking resistance. The latest data on this subject, however, point to the fact that the fatigue life of a reinforced plastic laminate is influenced by resin elongation. Laminates made with more flexible resins have longer fatigue life with respect to cracking than do those incorporating more brittle resins.

Fatigue tests have been run under constant load and constant deflection conditions at stress approximating 20 per cent of the ultimate flexural strength of the most rigid panels. It was found that endurance limit is not entirely proportional to strength but that the additional factor of resilience enters the picture. A point of interest is that polyester resins which give good impact resistance and higher endurance limits tend to absorb more water than do the more rigid resins. The qualities of impact resistance and low water absorption are fundamentally contravening, yet desirable, characteristics of a resin, just as are the broader characteristics of rigidity and resilience.

As would be expected, tensile rigidity must be compromised for the sake of impact resistance (Fig. 4). Material made with resin that is very rigid and has a flexural modulus of 1,500,000 psi at room temperature will have falling ball impact resistance of only 6 in. That is, at a height greater than 6 in. a ½ lb, 1½-in. diameter ball dropped on a 1/10-in. thick panel supported in a 5-in. diameter frame may cause cracking. If more resilient resin is used which will permit a laminate to pass the reverse impact test at 12 in., the modulus will drop to about 1,200,000 psi. In terms of vehicle requirements, a combination of adequate impact and better fatigue properties is obtained with laminates having a reverse impact rating of 12 in. or better. The modulus corresponding to this degree of resilience is sufficient to prevent excessive shake, bounce, or patter of 1/10-in. thick body outer panels. Furthermore, the overall stability of the body as a whole under these conditions is adequate; car doors remain locked even when the body is severely racked by the worst bumps.

The stiffness of reinforced polyester is decreased with increasing temperature (Fig. 5). A typical composition made with rigid resin will suffer a modulus drop from about 1,600,000 psi at 72° F to 800,000 psi at 180° F. One incorporating a resilient resin to enable it to meet a 12-in. reverse impact requirement will decrease from 1,300,000 psi to 500,000 psi. At temperatures between room temperature and 180° F, the more resilient material will be at an even greater disadvantage. However, because reinforced plastic has superior ability to damp out and shorten the duration of vibration periods, no objectionable degree of flexibility of a resilient, reinforced polyester body has been observed. Automotive body development experts report that Corvettes comprised entirely of reinforced plastic body panels and structural members made with resilient resins are about equivalent to average steel body convertible coupes with respect to shake, cowl movement, and torsional and beaming stiffness.

Just as the modulus of reinforced polyester is decreased with higher temperatures, low temperatures will cause the material to become brittle, thereby offering less impact resistance (Fig. 6). Accordingly, sufficient impact resistance is specified to insure adequacy at any temperature likely to be encountered in service.

While this material will fail by fatigue, the 20 per cent endurance limit has proved adequate in Chevrolet's designs, and no service fatigue failure has been reported. The limits to which stress could be increased, by virtue of decreased thickness, without encountering fatigue trouble has not yet been determined pending accumulation of additional developmental test data.

Standards established in seeking the optimum balance between resilience and rigidity have assured sufficient impact and flex cracking resistance without harmful impairment of structural rigidity. They are high enough to insure more than enough strength and acceptable fatigue life.

Bonded Joints Must Have Controlled Dimensional Accuracy

Some of the most difficult problems experienced in working with plastic car bodies have been basically ascribable to bonding practices and bonded joint design. Surface waviness found on exterior parts where a flange is bonded to the inside surface of an outer panel has been particularly disconcerting. Variations in the fit between the 2 surfaces result in varying bond line thickness and corresponding differences in the amount of resin shrinkage. The effect is a rippled appearance on the exterior, highly finished surface where the shrinkage of the polyester-base bond material pulls the outer panel into the flange in varying amounts. Even though this rippling may be only 0.001 in. in height or depth, it is apt to be noticeable due to the high-gloss finish of the body, especially in highlighted areas. Even the use of epoxide resins having very low shrinkage characteristics will not eliminate this completely if the bonded surfaces match poorly. The solution is, of course, to control dimensional accuracy of mating bonded parts closely and to remove any excess bonding material which is squeezed out of the joint. With the application of these bonding practices, this problem has been surmounted to a considerable degree.

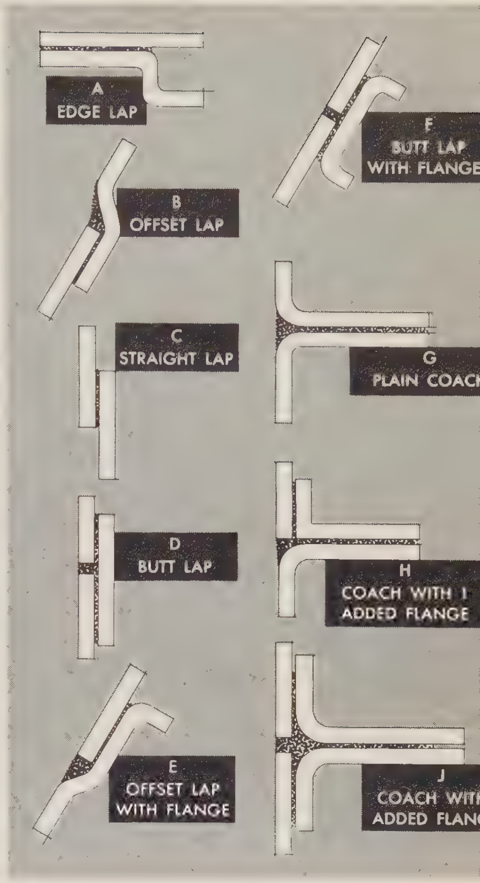


Fig. 7—Shown here are some of the more common joints used in bonding reinforced plastic panels together. Each of these joints has its particular merits relative to strength, cost, ease of assembly, and finishing. In general, balanced rigidity across a joint contributes greatly to its strength.

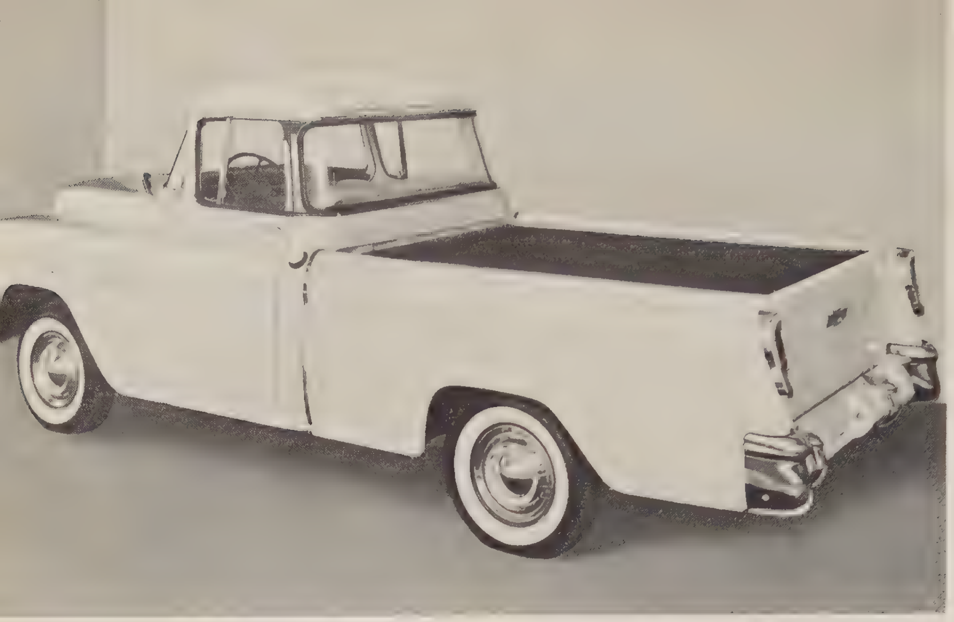


Fig. 8—In addition to the Corvette sports car body, Chevrolet also makes use of reinforced polyester resin for the rear hang-on type fenders of this pick-up truck called the Cameo Carrier. Offset lap joints (Fig. 7b and e) are used for the long horizontal joint which bonds together the 2 sections that make up the fender.

Patching over exterior joints presents other problems related to resin shrinkage. If the patch area is large, the volume decrease on curing is correspondingly large. The mass effect, meanwhile, creates high exothermic heat, making the patch tend to expand. If the internal residual stresses in these patches were high enough, the material would crack immediately. In this case it would be patched again, but there is a slight possibility that some internally stressed but apparently good joints might develop cracks in service after comparatively few light load applications. To cope with this problem Chevrolet uses low exotherm resins exclusively, which are filled with materials to absorb some of the heat generated on curing and to reduce the gross shrinkage. This problem can be alleviated further by reducing the volume of the patch over troublesome joints. Patch size is held to a minimum by improving dimensional accuracy and by redesigning to decrease the gaps between mating parts.

Tests Determine Best Joint Design to Satisfy Particular Need

These early problems precipitated an extensive study of joint design for reinforced plastic panels. A program of making and testing joints of various types (Fig. 7) was undertaken to avert any bond fatigue failures. The edge lap joint and plain coach joint (Fig. 7a and g, respectively) have handling advantages in assembly operations and are the least expensive of the types investigated. The coach joints (Fig. 7g, h, and j) provide a natural locating surface, and the finishing required is minimized. Tests of both static and fatigue strength properties have established that reinforced butt joints (Fig. 7d and f)are superior to even reinforced coach joints under loads simulating actual service conditions. Accordingly, butt joints are specified wherever feasible.

The offset lap joints (Fig. 7b and e) are used for the long, horizontal joint on the hang-on fender panels used on the Chevrolet Cameo Carrier (Fig. 8). The offset lap joint design has the advantage, like the coach joints, of naturally locating large panels for assembly. An offset lap variation (Fig. 7e) incorporates a flange which provides greatly added rigidity in the plane of the flange width. The flange can also be used as an attachment surface for lateral bracing. The straight lap style joint (Fig. 7c) is used only on interior structural parts which will not be seen and require no patching.

Each of these joint types has its particular merits relative to strength, cost, ease of assembly, and finishing. In general, balanced rigidity across a joint contributes greatly to its strength, and the strength of more rigid constructions is superior.

All of the tests completed to date have shown that static and fatigue test results correlate with one another for the bonded sections investigated. Tests both in tension and flexure under static and dynamic loading conditions have been run. Fatigue loads have been established at about 20 per cent of the ultimate static bond strength (for the weakest joint statically) and the joints compared at the same load.

Test data obtained thus far indicate that the relative bonding qualities of resins greatly differing in flexibility do not show corresponding differences either in load to failure or fatigue properties. Variations in residual stress due to curing conditions, however, would materially affect any comparison between 2 or more bonding materials.

Developmental work on bond joint design and bond materials continues. It is very important to the successful application of reinforced plastic in the automotive industry. By understanding the limitations of designing and manufacturing with these materials, engineers are better able to avoid the problems and effectively capitalize on the accompanying advantages.

Conclusion

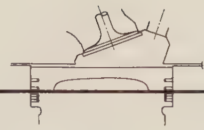
It must be remembered that, promising as it is, the new industry of reinforced plastics is in its infancy. There is much to be accomplished in the further development of material specifications and related testing. Technological advances will certainly provide new laminates of greater strength, lightness of weight, and with even better durability than those which can be produced at present. Undoubtedly, the development of reinforced plastic materials will profoundly influence the future thinking of automotive body designers.

Presently, economic factors are primary influences affecting the selection of reinforced plastic for automotive components, and the relationships of tooling cost, price, and unit volume must be thoroughly studied before a choice is made. For parts or models where volume is relatively low and, accordingly, tooling costs are high in proportion to total cost, reinforced plastic should definitely be given consideration.

The Chevrolet Corvettes rolling off the assembly line demonstrate that bodies composed of this new engineering material can be built on a production basis. Of greater significance is the fact that the public has enthusiastically accepted this plastic-bodied car.

It can be stated at this time that reinforced plastic has arrived as an important automotive body material for selected applications.

Matching Compression Ratio and Spark Advance to Engine Octane Requirements



By WILLIAM L. ALDRICH, JR.
Pontiac Motor Division

In recent years, automotive engineers have steadily increased the compression ratio of spark-ignition engines as the most fundamental approach to improving engine power and fuel economy. Compression ratio increases, however, have had to be geared to both chemical improvements in engine fuels and lubricants and mechanical improvements in such engine factors as air-fuel mixture ratios, valve timing, combustion chamber design, and ignition timing. Spark advance is a particularly important factor in the maximum utilization of compression ratio increases because of its close connection with engine octane requirements.

Automotive studies to solve the problem: how to improve engine power and fuel economy

THERE are 3 basic avenues open to the engineer through which he can improve the power output and fuel economy of a carbureted engine of given displacement: (a) by improving mechanical efficiency, (b) by increasing volumetric efficiency, and (c) by raising thermal efficiency. Considerable work has already been done regarding improvements in mechanical and volumetric efficiencies, and it is perhaps safe to say that only small gains in power output and fuel economy can be expected in the future from these 2 areas without a direct increase in cost. Thus, further improvement in thermal efficiency still appears to be the most promising area for future increases in power output and fuel economy. The most fundamental way to accomplish this is to increase compression ratio.

It is well known that the theoretical efficiency of the air-standard Otto cycle is dependent on compression ratio alone. While air-standard cycle efficiencies are higher than those actually obtained in an engine, such analyses show the potential improvement in thermal efficiency as a result of increasing compression ratio. Increased compression ratio results in more work done by a given air-fuel charge because of the greater expansion of the products of combustion prior to rejection from the engine cylinder. The increased thermal efficiency which results means that a greater percentage of fuel is converted to useful work. Tests have shown that such increases, if totally realized as fuel economy, can amount to as much as 6 per cent for each compression ratio increase, or on the basis of present tank mileage an improvement of approximately 1 mpg. For this reason, higher compression ratios are desirable; however, they also are more conducive to abnormal combustion (Fig. 1).

Effect of Chemical and Mechanical Improvements on Compression Ratio

Supression of abnormal combustion alone determines the maximum compression ratio of an engine. This is assuming, of course, that bearings and other structural parts of the engine are adequate. Precisely what this maximum useful compression ratio will be depends upon many factors. These can be listed under 2 broad categories: (a) chemical and (b) mechanical. Compression ratio increases must be accomplished by improvement in either one or both of these categories.

Chemical improvements are made possible through higher octane gasolines and improved engine oils. This is primarily the task of petroleum refiners who, incidentally, have made tremendous strides in this field in the past few years. It has been said that it costs a petroleum company approximately $1.5 million to effect an improvement of 1 octane number in high octane fuel. Thus, it can be seen how important it becomes that an engine utilize this fuel efficiently.

Mechanical improvements which allow compression ratio increases accomplish the same end as fuel octane increases and, therefore, are frequently referred to as *mechanical octane numbers.*

One distinct advantage of building mechanical octane numbers into an engine is that they enable compression ratio increases and, hence, better engine efficiency without any appreciable increase in the present chemical octane level of gasoline. Due to the large number of earlier model low-compression ratio cars still on the road and because it is not economically feasible for the petroleum industry to make rapid octane increases, the advantages of increased compression ratios would necessarily come slower if reliance were placed entirely on chemical octane improvement.

Some of the factors which affect mechanical octane numbers and, in turn, permit increased compression ratios are air-fuel mixture ratio, car-engine-transmission relationship, valve timing, combustion chamber configuration, and spark timing. Much could be said about all of these factors, but only combustion chamber design and spark timing will be discussed. Generally, higher compression ratios accomplished through improving these 2 mechanical factors produce gains in both power and fuel economy.

Combustion Chamber Design

Through combustion chamber design (Fig. 2) engine designers seek to construct the chambers so that the rate of burn is increased and the charge completely consumed before the last portion of gas to burn (end gas) has had time to condition itself to burn instantaneously. Two physical factors which facilitate short combustion periods are: (a) combustion chamber compactness and (b) central spark plug location. Other desirable factors are concentration of the charge at the point of ignition and a large surface-to-volume ratio or *quench* area where the last portion of the charge is consumed. Another desirable feature from the standpoint of short combustion time is turbulence, a characteristic which has brought to light many unconventional combustion chamber designs.

Spark Timing

While the compression ratio of a new

Fig. 1—This chart, prepared and published by the Combustion Chamber Deposits Group in the Motor Fuels Division of the Coordinating Research Council, defines the various terms associated with Otto cycle engine combustion and shows their interrelation.

TERMS FOR USE IN OTTO CYCLE ENGINE COMBUSTION

NORMAL COMBUSTION

A combustion process which is initiated solely by a timed spark and in which the flame front moves completely across the combustion chamber in a uniform manner at a normal velocity. In such a process there is no sudden release of energy from the fuel-air mixture, nor are there any auxiliary sources of ignition from combustion-chamber deposits, hot spark plugs, overheated valves, or other hot surfaces within the combustion chamber. Engine roughness associated with high gas loads and mechanical deflections of engine components can accompany normal combustion.

ABNORMAL COMBUSTION

A combustion process in which a flame front may be started by hot combustion-chamber surfaces either prior to or after spark ignition, or a process in which some part, or all, of the charge may be consumed at extremely high rates. This term, therefore, includes any surface ignitions of the charge, and it includes ordinary knock or knock which is induced by surface ignition phemomena, either prior to or after spark.

SPARK KNOCK*

A knock which is recurrent and repeatable in terms of audibility. It is controllable by the spark advance; advancing the spark increases the knock intensity and retarding the spark reduces the intensity. This definition does not include surface-ignition induced knock.

SURFACE IGNITION (HOT SPOTS - COMBUSTION-CHAMBER DEPOSITS)

Surface ignition is the initiation of a flame front by any hot surface other than the spark discharge prior to the arrival of the normal flame front. The flame front or fronts so established propagate at normal velocities. This phenomenon can be further subdivided into preignition and postignition

PREIGNITION

Surface ignition before the occurrence of normal spark.

POSTIGNITION

Surface ignition which occurs after the passage of the normal spark.

KNOCKING* SURFACE IGNITION

Knock which has been preceded by surface ignition. It is not controllable by spark advance. It may or may not be recurrent and repeatable.

RUN-ON

Continuation of engine firing after the electrical ignition is cut.

NON-KNOCKING SURFACE IGNITION

Surface ignition which does not result in knock.

RUNAWAY SURFACE IGNITION

Surface ignition which occurs earlier and earlier in the cycle. This phenomenon is generally caused by overheated spark plugs, valves, or other combustion-chamber surfaces. Generally it is not caused by floating deposit particles or deposits adhering loosely to the combustion-chamber walls. This is the most destructive type of surface ignition. It can lead to serious overheating and structural damage to the engine.

WILD PING

Knocking surface ignition characterized by one or more erratic sharp cracks. It probably is the result of comparatively early surface ignition from deposit particles.

RUMBLE

A low-pitched thudding noise different from knock and accompanied by engine roughness. One of the causes probably is the high rates of pressure rise associated with very early ignition or multiple surface ignition.

*KNOCK - The noise associated with autoignition[1] of a portion of the fuel-air mixture ahead of the advancing flame front. The flame front is presupposed to be moving at normal velocity

With this definition the source of the normal flame front is immaterial - it may be the result of surface ignition or spark ignition.

[1]AUTOIGNITION - The spontaneous ignition and the resulting very rapid reaction of a portion or all of the fuel-air mixture. The flame speed is many, many times greater than that which follows normal spark ignition. There is no time reference for autoignition.

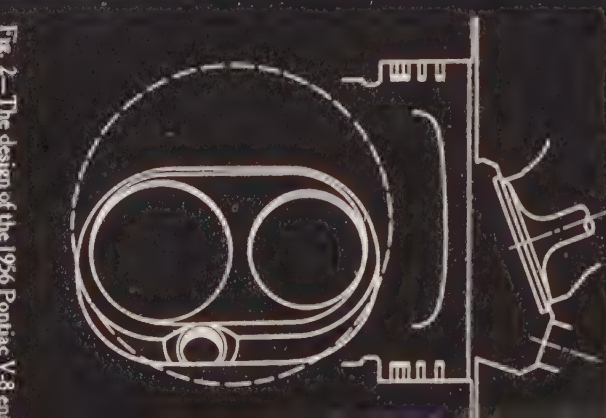


Fig. 2—The design of the 1956 Pontiac V-8 en combustion chamber is such that most of charge is concentrated close to the spark while the last portion of the charge is consu in a high surface-to-volume area (*quench* a for purposes of maximum cooling. The de also minimizes susceptibility of spark plug fou by extending the combustion chamber over top of the piston in this vicinity. This serv deflect any oil that may pass by the rings a from the electrodes of the spark plug.

engine is selected to utilize fully the fuel anticipated to be available at the time the engine is scheduled to be in production, the effectiveness of the compression ratio depends a great deal upon how well the distributor performs its function of providing proper spark advance at all speeds and loads. For a *clean* engine, one with no carbon deposits, not limited by spark knock, there is a definite spark advance at which the maximum torque the engine is capable of producing is obtained. This is the advance the distributor should provide whenever there is a demand for full-throttle power.

While this spark advance provides maximum power at full throttle, it does not provide maximum fuel economy at part throttle. Since the majority of all driving is done at part throttle, to achieve maximum conservation of gasoline, it is essential that the spark be changed to provide maximum economy at this operating condition. Because of the relatively close limits of air-fuel ratios that will readily ignite and burn evenly and completely, it is necessary that the quantity of air, as well as fuel, be decreased at reduced power. This would suggest that the air-fuel ratio at part throttle would approximate that at full throttle. Actually, however, the part-throttle mixture can be sufficiently leaner to cause a considerable slowing down in rate of burn. This, coupled with slower burn due to such factors as greater exhaust gas dilution and less density, means that spark advance at part throttle must be greater than at full throttle. The distributor, therefore, must furnish a second and higher spark advance to provide maximum fuel economy at part throttle.

These 2 spark advances can be accomplished by means of a centrifugal advance which depends upon engine speed and a vacuum advance which depends upon intake manifold vacuum. The centrifugal advance is used to provide proper spark for best power, and centrifugal and vacuum advances are combined to provide best spark for fuel economy. Exactly how these spark advance curves are determined for a specific car-engine combination can, perhaps, be illustrated best by a case in point. For this purpose an engine representative of those produced in 1956 will be used.

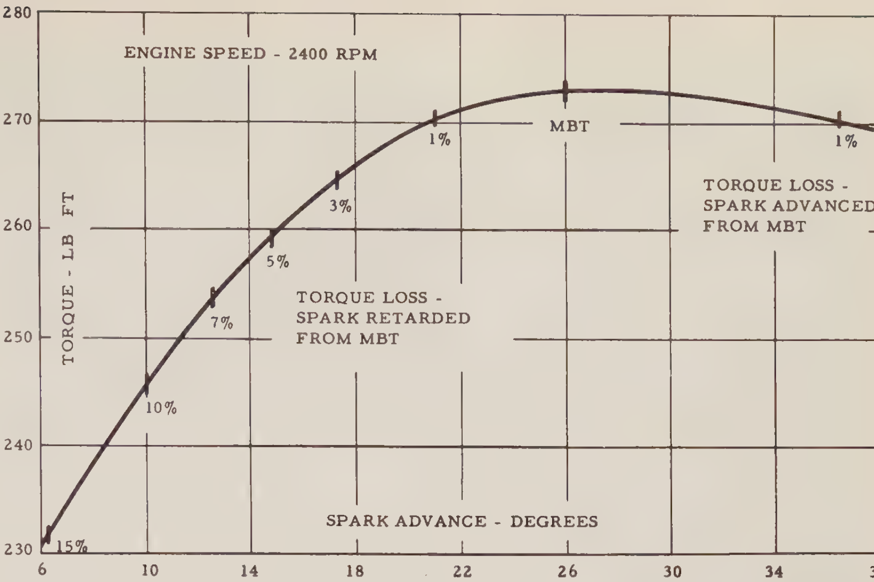


Fig. 3—As part of the overall GM Test No. 6A, performed to obtain maximum power and spark sensitivity from an engine without limitations of spark knock, an engine is run up to its limiting speed at 200 rpm increments, starting at 600 rpm. At each selected increment of engine speed the spark is advanced in 2° steps, and the torque obtained at each spark advance setting is recorded. Shown here are the results of a test performed on a representative engine at 2,400 rpm. The resulting spark-torque curve shows that, in the vicinity of maximum torque, the engine is relatively insensitive to further spark advance. Particular interest in this test is paid to the point at which minimum spark advance at maximum torque is obtained. This point is designated as the minimum spark for best torque (MBT).

Centrifugal Spark Advance for Best Power

The engine test used by General Motors engineers to determine maximum power and spark sensitivity of the engine design without being limited bv spark knock is GM Stock Engine Test No. 6A. This test consists of running an engine at full throttle in 200 rpm increments from 600 rpm to limiting speed. At each increment of engine speed the spark is advanced in 2-degree steps and the torque recorded. The result is a series of spark-torque curves which show the minimum spark advance setting for various percentages of torque loss at each increment of speed.

If a spark-torque curve for the representative engine at 2,400 rpm is examined (Fig. 3), it will be noted that in the vicinity of maximum torque the engine is relatively insensitive to spark advance.

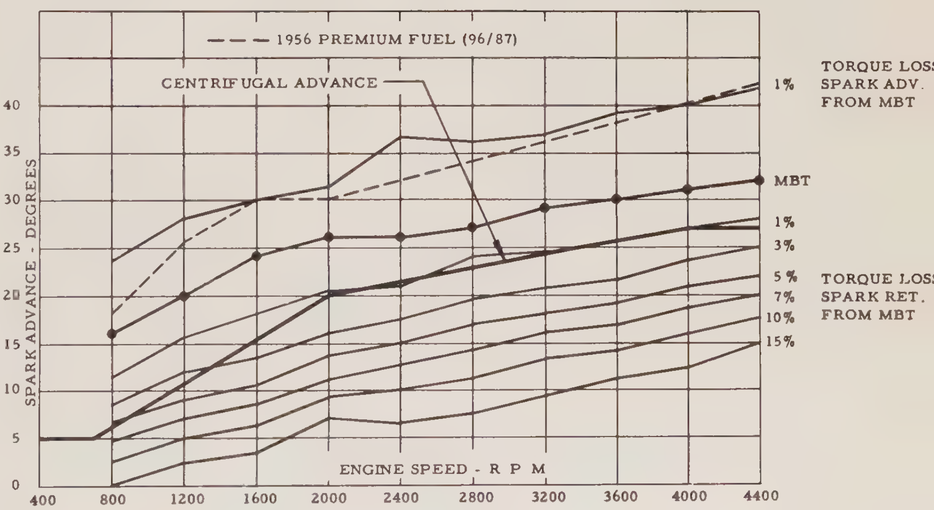


Fig. 4—This series of curves which indicate the sensitivity of a representative 1956 engine to changes in torque with spark advance is referred to as the spark frameworks portion of GM Test No. 6A. The curves represent a consolidation of the various percentage torque losses extracted from the individual spark-torque curves (Fig. 3) resulting from tests performed on the engine at specified increments of speed. Since the GM Test No. 6A is performed with a non-knocking fuel, it is essential that the spark advance necessary for borderline spark knock with the fuel the engine is designed to use be known. This spark advance is shown by the dashed line. The heavy, solid line is the centrifugal spark advance which the distributor, designed for the representative engine, would provide when measured on a bench test machine and initially set at 5° BTC.

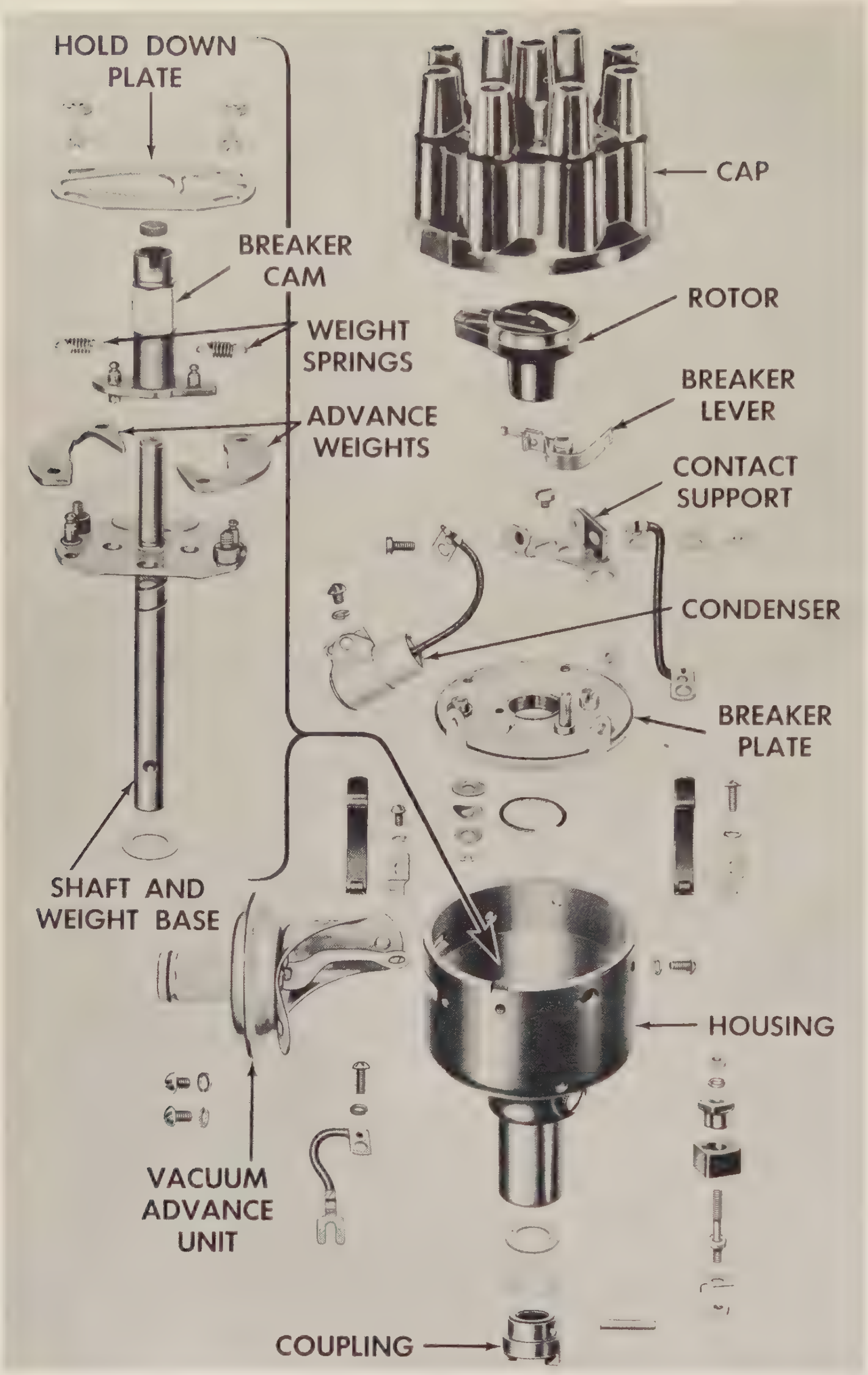


Fig. 5—This exploded view of a distributor shows how the breaker cam is concentric with and independent of the distributor shaft and weight base. Centrifugal advance to provide proper spark for best power is obtained by the 2 similar advance weights which swing outward, due to centrifugal force against the tension of the weight springs. The outward movement of the weights advances the breaker cam ahead of the distributor shaft and, therefore, the camshaft, crankshaft, and piston.

Since no benefit is realized from additional spark advance, there is interest only in the point at which minimum spark advance at maximum torque was obtained. This point is referred to as the minimum spark for best torque (MBT).

From the maximum torque figure at each increment of engine speed various percentages of torque loss from 1 per cent to 15 per cent can be readily calculated and the optimum spark advance "picked-off" the spark-torque curve (Fig. 3). Collectively, these curves of constant per cent torque loss form the frameworks portion of the GM Test 6A, which indicates the sensitivity of an engine to changes in torque with change in spark advance (Fig. 4).

If the centrifugal spark advance curve supplied by the distributor on an engine were coincident with the MBT curve, then maximum torque would be obtained at all speeds. The selected distributor centrifugal advance shown by the heavy black line (Fig. 4), however, does not fall on this MBT line. Instead, the centrifugal advance "cuts-in," or begins, at 700 rpm with a torque loss of approximately 5 per cent at 800 rpm, decreases to 1 per cent at 2,000 rpm, and remains close to 1 per cent from there on up to the limiting speed of the engine.

There are very definite reasons for this. First, it is impractical to earmark a dynamometer and engine for the single purpose of measuring centrifugal spark advance under actual operating conditions. Advance specifications, therefore, are made with reference to a bench test machine. While the advance, as measured on this machine, closely duplicates that obtained on the engine, experience has shown that actual engine advance is from 2° to 4° higher at high engine speeds. For this reason, plus a 2° allowance for a high-limit distributor, the centrifugal spark advance specified above 2,000 rpm is always below MBT by at least this amount which, for simplicity, is considered equal to the 1 per cent torque loss line. Below 700 rpm there is no centrifugal advance. Initial spark timing, therefore, can be set at any speed below 700 rpm and in this particular example should be set 5° before top dead center (BTC) to properly index the distributor's centrifugal advance mechanism with engine requirements. In the range from 700 rpm to 2,000 rpm torque loss also is sustained; here, however, the primary reason is to match the octane requirements of the engine to the fuel expected to be used.

Superimposed on the frameworks portion of the GM Test 6A results (Fig. 4) is a borderline-knock curve of a representative 1956 premium fuel. This curve shows the maximum spark advance at which this fuel will operate knock-free in the representative engine, and closely parallels the distributor advance curve. This signifies that, when the engine is operated on premium fuel, the selected

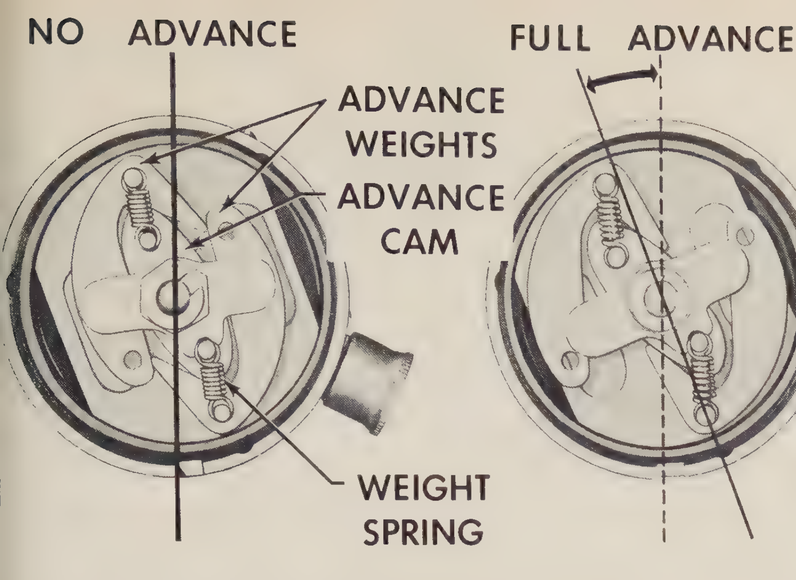


Fig. 6—These 2 views which illustrate the centrifugal advance mechanism show the distributor shaft and centrifugal advance weight base occupying the same position relative to the body of the distributor at positions of no advance and full advance. When the advance weights move outward to the full advance position, the centrifugal advance cam, which is fastened to the breaker cam, is rotated by the advance weights ahead of the distributor shaft and weight base through an arc shown by the arrow.

centrifugal advance will be approximately 12° retarded from incipient knock at all engine speeds. In other words, the engine will have an even cushion of 12° clean. When the engine acquires deposits, however, the cushion is much less and may take on a negative value, as revealed by octane requirements tests.

Idle quality of the engine also is directly influenced by low-speed spark advance. To obtain MBT spark at 800 rpm, initial spark timing, of necessity, would have to be 15° BTC. This is well above the optimum advance for best idle; hence, it is advantageous from this aspect, also, to retard the spark at low speed. Furthermore, modern automatic transmissions have helped lessen the significance of torque loss at low speed, since they tend to raise the minimum engine speed at which the throttle can be opened fully.

Centrifugal Advance Mechanism

Centrifugal advance is accomplished mechanically by means of 2 weights which swing outward against spring tension by centrifugal force and, in doing so, move or advance the breaker cam ahead of the distributor shaft. The desired centrifugal advance curve (Fig. 4) is achieved through proper selection of centrifugal advance weights, advance cam contours, and weight springs (Figs. 5 and 6).

Vacuum Spark Advance for Best Fuel Economy

In the selection of vacuum spark advance for best economy, the first step is to conduct fuel economy tests. These tests are conducted with the engine in high gear and at car speeds from 20 mph to 80 mph, in increments of 10 mph. The economy tests are run at sufficient numbers of spark advance settings at each speed to bracket maximum fuel economy. A series of spark curves (Fig. 7), commonly known as spark *fish-hooks*, are obtained from which it is possible to select the minimum spark advance for maximum fuel economy. Unfortunately, this spark advance is considerably higher than MBT spark, sufficiently so at low speeds to cause objectionable *surge*. Consequently, best economy spark advance in the low-speed range must necessarily be kept below maximum economy advance by an amount sufficient to insure surge-free operation.

With information from the spark fish-hook curves plus engine speed and distributor vacuum at road load, it is possible to select the distributor vacuum advance. Since it is known that spark fish-hooks yield total spark advance, distributor vacuum advance, therefore, must equal the difference between total and centrifugal plus initial advance (Table I). The next step is to select a vacuum advance unit which most closely provides the necessary advance with the distributor vacuum available at the carburetor of the representative engine. A plot of points of best economy spark advance against distributor vacuum available at the carburetor is included along with specifications recommended on the basis of these points (Fig. 8). It may seem that this vacuum advance selection is unduly low, but it should be remembered that the advance necessary

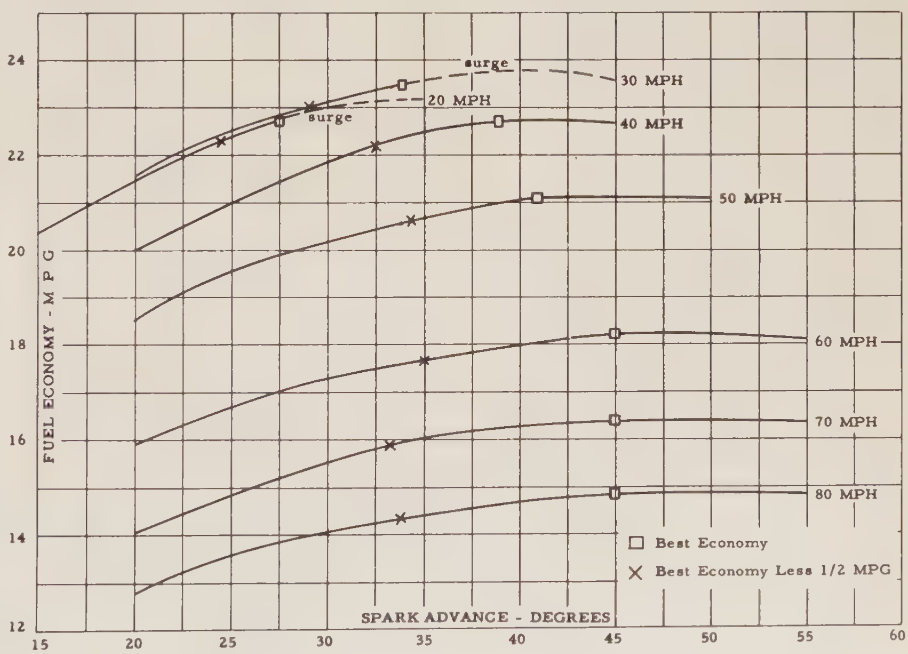


Fig. 7—From fuel economy checks run on a representative 1956 engine operated in fourth gear at speeds ranging from 20 mph to 80 mph, a series of curves called spark *fish-hooks* are obtained, which make possible the selection of minimum spark advance for maximum fuel economy. The optimum spark advance for maximum economy is considerably higher than the minimum spark for best torque and causes considerable surge at low car speeds. As a result, the optimum spark advance selected for best economy, as indicated by the square, is below the advance for maximum fuel economy by an amount sufficient to insure surge-free operation. The spark advance, indicated by a cross on each curve, is at a fuel economy value of ½ mpg below the setting for best surge-free economy.

VACUUM ADVANCE CALCULATIONS

			Spark Advance for Best Economy			Spark Advance for Best Economy Less ½ mpg		
Car Speed	Engine Speed	Distributor Vacuum (Road Load)	Total (Spark Fish Hooks)	Centrifugal (GM Test No. 6 A)	Vacuum (Required)	Total (Spark Fish Hooks)	Centrifugal (GM Test No. 6 A)	Vacuum (Required)
20 mph	770 rpm	11.5 In. Hg	27½	6	21½°	24°	6°	18°
30	1,180	19.0	34	10½	23½	29½	10½	19
40	1,570	18.0	39	15	24	32½	15	17½
50	1,930	17.5	41	19	22	34	19	15
60	2,300	16.0	45	21	24	35	21	14
70	2,660	15.0	45	22½	22½	33	22½	10½
80	3,040	13.0	45	23½	21½	33½	23½	10

Table I—The vacuum advance necessary to provide maximum surge-free fuel economy is calculated as the difference between the total spark advance and centrifugal advance. For example, at a car speed of 60 mph (2,300 rpm) the total spark advance for best economy is equal to 45° as determined from the spark *fish-hook* curve for this particular car speed in Fig. 7. The centrifugal advance at this car speed which will insure knock-free operation is equal to 21° as determined from the centrifugal advance curve of Fig. 4. The required vacuum advance, therefore, for best economy is equal to the difference between these 2 values or 24°. The vacuum advance required at this car speed for a ½ mpg loss from best economy is calculated in the same manner using the curves of Figs. 7 and 4 respectively for total advance and centrifugal advance values.

for ½-mpg loss from maximum surge-free economy essentially establishes the limits of the vacuum advance curve. Nearly all points fall within or below the band (Fig. 8); hence, loss in economy would seldom be greater than ½ mpg from optimum. Not considered here, but also of importance in the selection of vacuum advance, is an allowance for production tolerances in the mass-produced distributor.

Vacuum Spark Advance Mechanism

The vacuum advance mechanism (Fig. 9) used to achieve the advance for the representative engine contains an air-tight diaphragm which is linked to the breaker plate. The spring-loaded, or air-tight, side of the diaphragm is connected by a tube to an opening in the carburetor. This opening is on the atmospheric side of the throttle valve so that no vacuum advance will take place when the throttle is in the idle position. When the throttle is opened, however, it swings past the vacuum opening. The intake manifold then can function through this passage on the vacuum advance diaphragm, causing the spring to be compressed and the breaker plate, which is supported on bearings and independent of the housing, to be rotated in the direction opposite to breaker cam rotation. Close examination of these 2 actions, centrifugal advance and vacuum advance, reveals them to be cumulative. Thus, at any particular engine speed there will be a certain centrifugal advance due to speed plus a possible additional advance resulting from vacuum conditions in the intake manifold—a function of load or throttle opening.

Cut-in vacuum is set sufficiently above that encountered at full throttle to insure that there will be no vacuum advance at this condition. The minimum vacuum at which full advance is desired sets the maximum advance. These 2 conditions define the advance curve and determine what the initial spring tension and spring rate will be.

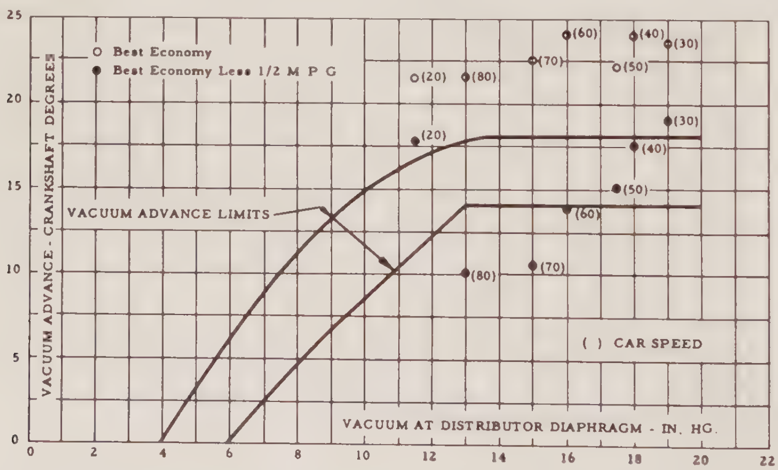


Fig. 8—This plot of vacuum advance requirements for both best economy and best economy less ½ mpg at car speeds ranging from 20 mph to 80 mph shows that nearly all of the best economy less ½ mpg advance points are within or below the vacuum advance limits band. This indicates that, in level-road constant-speed operation, loss in economy will seldom be greater than ½ mpg from the optimum. The vacuum advance limits adequately span and allow for production variations in the distributor and are those recommended to provide best economy while at the same time maintaining a reasonable spark retard from low-speed surge.

Octane Requirements

Once centrifugal and vacuum advance data are known, the octane requirements of the engine-transmission-car combination can be determined. It is well known that engine deposits can decrease power as much as 10 per cent to 15 per cent, decrease fuel economy 3 per cent to 4 per cent, and increase octane requirements from 6 to 10 numbers. The decreases in power and fuel economy, while definitely not desirable, will have no detrimental effect on engine life or operation. Octane requirements, however, are a different story.

Effect of Engine Deposits on Octane Requirements

Carbon deposit formation in an engine does 3 things: (a) decreases clearance volume, (b) insulates or retards rejection of heat to the relatively cool combustion chamber surfaces, and (c) changes the chemical and physical composition of the surface in contact with the air-fuel charge. All of these factors, especially thermal insulation, tend to raise the octane requirement. Exactly how much the octane requirement increase will amount to and what the maximum requirement will be depends again on the engine-transmission-car combination, the severity of the carbon accumulation schedule, and the appraisal procedure.

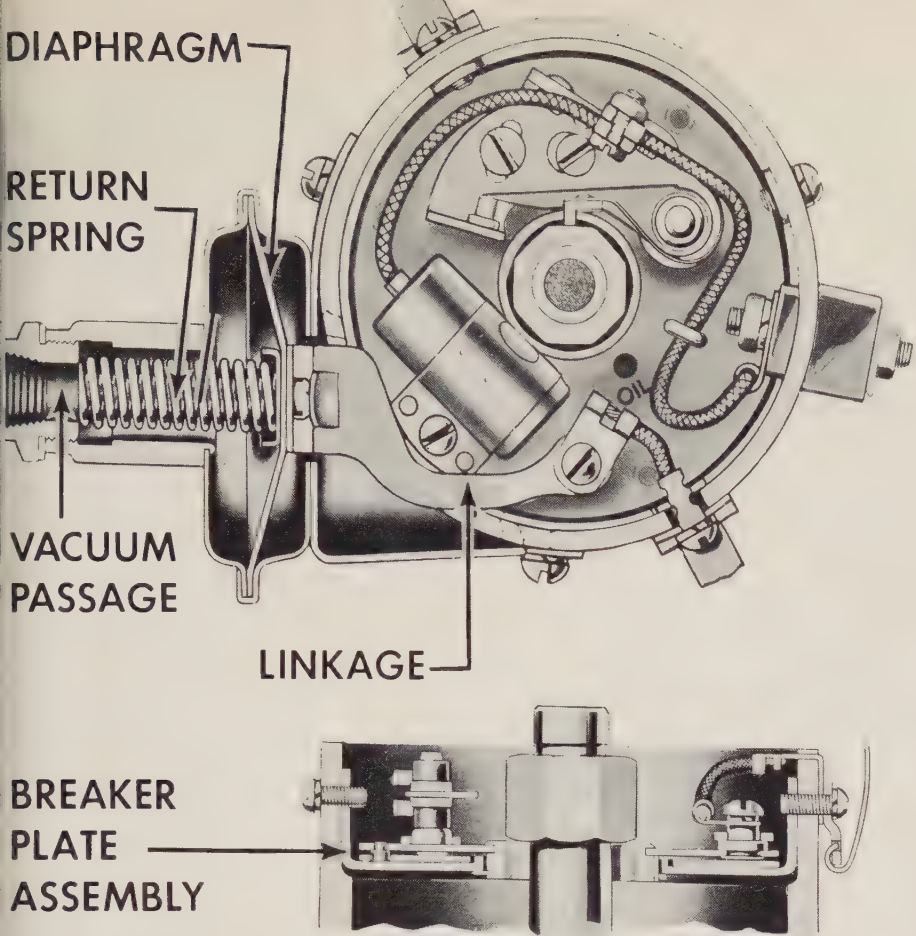


Fig. 9—The vacuum advance mechanism contains an air-tight diaphragm which is linked on one side to the breaker-plate assembly and on the other side to a return spring fitted inside a vacuum passage leading to the carburetor. Under part-throttle conditions the high manifold vacuum acting on the diaphragm overcomes the return spring tension, which causes the breaker-plate assembly to rotate in a clockwise direction. Since the centrifugal advance mechanism rotates the breaker cam in a counter-clockwise direction, the total advance is the sum of the 2 separate advances.

In preparing a car for octane schedule tests, Pontiac Motor Division engineers first make certain that the car has a mean-flow carburetor and a mean-limit distributor centrifugal advance, that all carbon deposits have been removed from the engine, and that the average compression ratio, as well as spread, is within acceptable limits. For the test, the engine oil is usually SAE 10W, engine coolant is a 50 per cent solution of permanent anti-freeze, the engine water thermostat has a start-to-open temperature of 170° F, and the fuel used is that expected to be available at the time the engine is produced. Selection of oil, coolant, and thermostat are not for the intended purpose of simulating the worst condition but are chosen primarily because they allow year-around testing.

With completion of this preparatory work, the car is then placed on a GM Proving Ground Octane Schedule "A" or "B" test depending on whether the car has 3-speed synchromesh transmission or a Hydra-Matic automatic transmission. These schedules, which are the same except for gear shifting, are representative of suburban-type driving with speed limited to a maximum of 50 mph. Obviously, no prescribed schedule can satisfy all driving conditions; however, this carbon accumulation schedule is sufficiently severe to produce an octane requirement that will encompass the majority and give reproducible results.

Appraisal Tests to Determine Octane Requirements

While Pontiac personnel drive the test cars on a regular schedule at GM's Milford, Michigan, Proving Ground, the octane appraisals are made by engineers of the Fuels and Lubricants Department of the GM Research Staff. The appraisal procedure, developed by Research Staff engineers, is widely used within General Motors and is such that it is possible to compare the octane requirements of various makes of cars. These appraisals are made using *commercial reference* fuels in even steps of 2 Research Octane Numbers (RON). By *commercial reference* it is meant that the distillation curve, lead content, and sensitivity of the test fuel closely match the present trend in commercial fuels. These reference fuels are carried in 3-gal cans in the test car and are introduced into the engine by means of a 3-way valve which allows the gasoline tank to be by-passed. Octane appraisals are made at the start of a test, at 1,000, 2,000, and 3,000 miles, and daily thereafter (approximately every 450 miles) until octane requirements have stabilized. Experience has taught that engine deposits stabilize in the vicinity of 3,000 carbon miles. Consequently, all appraisals made beyond this figure should produce the same requirement. There are other uncontrollable factors, however which cause this requirement to fluctuate. Temperature, humidity, barometric pressure, and wind are some of these variables. In order to compensate or dampen out these and others as much as possible, 7 to 10 appraisals (usually 1 each day) are made beyond the 3,000 carbon-mile mark with sufficient miles acquired in between on the carbon accumulation schedule to replace any carbon deposits which might have been knocked out by the previous appraisal.

The car-engine-transmission octane requirement appraisal procedure consists of a series of tests which become increasingly severe. First, a series of level-road, maximum-throttle accelerations are made in third or fourth gear—depending on whether the car is equipped with a synchromesh or a Hydra-Matic automatic transmission—with normal coast-downs allowed between accelerations. Following this, a series of maximum-throttle investigations in high gear are made on 7 per cent and 11 per cent grades.

The next portion of the appraisal schedule covers part-throttle investigations on the same 7 per cent and 11 per cent grades. The last test in the appraisal procedure consists of a second or third gear acceleration—depending on whether the car is equipped with a synchromesh or Hydra-Matic automatic transmission—from 15 mph to 45 mph at maximum throttle on the 11 per cent grade.

If at any point during the appraisal a fuel should audibly *fail* by causing either spark knock or knocking surface ignition (KSI), a fuel 2 octane numbers higher is used and the immediately preceding portion of the test re-run. If this fuel also *fails*, then a third fuel, again 2 num-

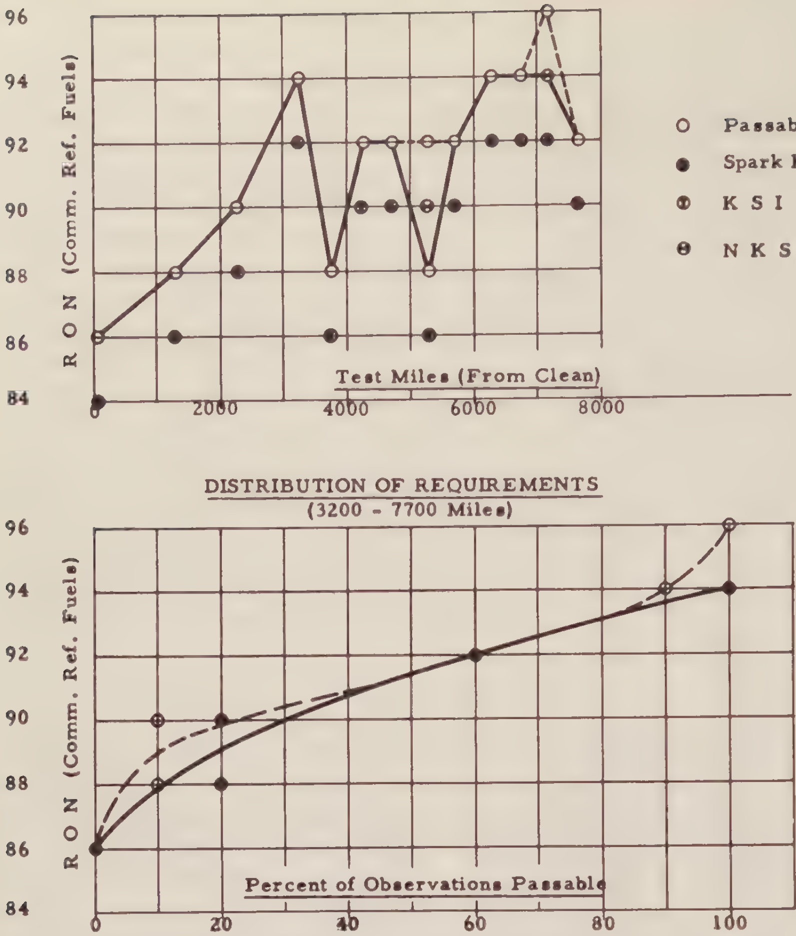


Fig. 10—Results of daily appraisals of engine octane requirements are summarized into curves from which a fuel for acceptable, abnormal-combustion-free operation is selected. The curve at the top shows the 2-octane step *pass* and *fail* fuels used for each appraisal. The acceptable, audible octane requirements curve (solid line) is defined by the series of lowest octane 2-step fuels which did not fail from either spark knock or knocking surface ignition (KSI). The acceptable, maximum octane requirements curve (dashed line) is defined by the series of lowest octane 2-step fuels which did not fail from non-knocking surface ignition (NKSI) as well as spark knock and KSI. The bottom curve summarizes the distribution of the stabilized portion of the daily octane requirement appraisals recorded at 3,000 carbon miles and above. Pontiac engineers use the 50 per cent, and sometimes the 90 per cent, audible satisfaction points on the curve shown to define the average acceptable octane requirement of the engine-transmission-car combination. The 50 per cent satisfaction point for the representative 1956 engine-transmission-car combination, upon which the curves are based, is equal to a 91.4 RON commercial reference fuel, which closely matches commercially available fuels. This means that a 91.4 RON fuel will satisfy the specific engine-transmission-car combination with respect to all audible abnormal combustion 50 per cent of the time. Since the average of all forecasts obtained from the various available sources indicate that the average value of premium fuel for the year in which the engine is to be in production will be a maximum of 96 RON and a minimum of 92 RON, it can be deduced that the initial selection of compression ratio and distributor advance for the representative engine was good. The engine should generally give non-knocking performance when operated on commercially available fuels, while at the same time will utilize fully the octane value of the fuel it was designed to use. If the test results had indicated that the 50 per cent satisfaction requirement exceeded the octane value of available premium fuel, a reduction in octane requirement would have to be achieved by such means, for example, as reducing the compression ratio or retarding the spark. Conversely, had the 50 per cent satisfaction point been too low, full utilization of the fuel could be achieved only by increasing the compression ratio. For the specific results shown here, 8 of the stabilized audible failures were attributed to KSI. Retardation of spark advance, in this case, would have little beneficial results to correct the situation.

bers higher, is used until a fuel is found which will satisfy the complete schedule. This fuel then is the lowest 2-step octane fuel which will audibly satisfy the appraisal schedule. What the test engineer attempts to do during these appraisals is to select 1 fuel that will *fail* while the next higher octane fuel will *pass*. If the engineer succeeds, the minimum acceptable octane requirement is determined by using only 2 fuels. The advantage in doing this is that carbon deposit disturbance, occasioned by the abnormal combustion of the fuels that failed, is kept to a minimum. Pontiac engineers consider a spark knock of *light* intensity (that which would just attract the attention of the average driver) or greater as constituting fuel failure. Knocking surface ignition, if present, constitutes failure.

The minimum octane value of the fuel required by the engine for noise-free operation—commonly referred to as its audible requirement—is on some appraisals too low to satisfy non-knocking surface ignition (NKSI). This is particularly true at high compression ratios and for sensitive fuels, and present indications are that both compression ratio and sensitivity will continue to increase. When NKSI is observed on the lowest 2-step octane fuel which satisfies the audible requirement for the complete appraisal schedule, that portion of the schedule where NKSI was observed is re-run with progressively better 2-step octane fuels until a fuel is found which satisfactorily eliminates it. This fuel, thus eliminates all abnormal combustion encountered by the engine throughout the entire appraisal schedule and is called its maximum requirement. Curves summarizing the above appraisals are shown in Fig. 10.

While the maximum requirement is always determined, it is currently not considered in defining the engine requirement. There are 2 reasons for this: (a) it is not customer objectionable and (b) Pontiac has yet to experience any detrimental engine effects from NKSI. If future engine designs show NKSI to be detrimental, then data gained thus far will have important reference value and the maximum requirement will then define the engine requirement.

Summary

Ignition timing and combustion chamber design are principal mechanical factors in building spark-ignition engines of higher compression ratio; the octane value of commercially available fuel is the principal chemical factor. Since increased compression ratio is the key to higher thermal efficiency, the overall objective of engineers is to design passenger car engines using the highest possible compression ratio that will allow freedom from abnormal-combustion operation, using fuel available at the time the engines are in production.

To meet this objective, close attention must be given to increasing mechanical octane numbers, principally through combustion chamber design and proper ignition timing. Combustion chamber shapes should be compact, have high *quench* characteristics, and produce high turbulence. Distributors must be designed to regulate ignition timing so as to provide optimum spark advance for both power and economy at part- and full-throttle.

Some Problems Encountered in Exploiting Inventions

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Patent Section
Central Office Staff

The patentee should investigate his rights to make, use, and sell his invention

THE granting of a patent covering an invention is not a key for automatically unlocking the door to exploitation of the invention. If the patentee cannot commercialize the invention himself, he may await approaches by others who may become aware of the patent, or he may try to interest others, such as manufacturers, in commercializing it.

The experiences of inventors in following the latter plan may explain why many patents never become used by anyone and the patentees gain no reward for their efforts. Many reasons have been given for rejecting patents so offered, of which the following are representative examples.

Ease of Manufacture and Market Potential Are Typical Problems

Assuming that the invention covered by the patent relates to an article of manufacture, such new articles must possess several qualities, such as utility, ease of manufacture, attractive price, and the like, to gain success. If the article is so complicated that it does not lend itself to volume production, then its chances of success are materially reduced. In addition, if extremely close tolerances and the like are required for the manufacture of the article, again its chances are reduced. Complexity adds to the cost of manufacture, which can be a deciding factor since high manufacturing costs can compel such high selling prices that the article cannot meet competition.

Even though the invention may be sound theoretically, often it will be found that in the form presented by the inventor it will not perform the function for which it was intended. Often this is due to lack of thorough knowledge of the field by the inventor before he approached the problem which he was endeavoring to solve. In addition, tests may prove that the article when put into actual service cannot perform in the manner in which it was intended to perform and, therefore, does not solve any problems.

Investigation may prove that the potential market for a supposedly new article of manufacture is so small as not to warrant the cost of tooling for production and other necessary expenses for placing the article on the market. Some inventors have investigated the potential market for an article before going to the expense of patenting the same, so that these considerable expenses have been saved and the article forgotten by the inventor.

If the patentee is in a position to commercialize his inventions himself, he will be well advised to have a patent investigation made by his patent attorney for the purpose of determining whether the way is clear for such commercialization. This investigation entails the study of unexpired patents in the same field and in fact is determinative of the right of the inventor to manufacture, use, or sell his invention. Patentees often are confused on this point since many believe that the grant of the patent automatically authorizes the patentee to make, use, and sell his invention. This has been true particularly prior to 1953, since patents granted before that date included in the original patent delivered to the patentee the grant of the exclusive right to make, use, and sell the invention. Having such grant in his possession the patentee can be faced by the seeming paradox of having the exclusive right to make, use, and sell his invention, but being unable to do so without subjecting himself to possible suit for patent infringement.

This seeming paradox can be clarified by the following illustration. Reverting to bygone days, assume that someone of inventive mind felt the need for some article which would serve as a support in elevated position above a floor. This individual invented a table for which a patent was obtained. One of the claims of the patent—and patent claims measure the scope of the invention—might read as follows:

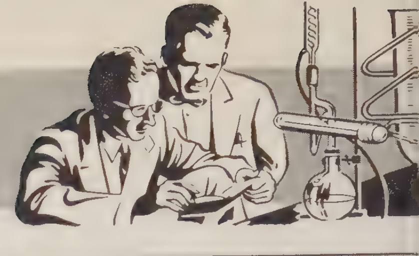
> As a new article of manufacture, a table comprising a member providing a generally plane surface, and a plurality of legs depending from said member for supporting said member in spaced relation to a supporting structure.

The table, being new, met with instant success, and the inventor automatically acquired to himself a ready market.

Having observed the utility of the table, another inventor conceived the idea of providing it with a movable tray, or drawer, in which various articles could be placed for concealment beneath the surface of the table but which would be readily accessible by moving the drawer outwardly from its position beneath the table. The support of this drawer could be by slideways, by pivotable connection, or by any other suitable arrangement. The second inventor, therefore, attempted to obtain a patent for his invention, and, since the new arrangement presented novelty, his efforts were rewarded by the grant of a patent. This second patent may have as one of its claims the following:

> As a new article of manufacture, a table comprising a member providing a generally plane surface, a plurality of legs depending from said member for supporting said member in spaced relation to a supporting structure, and a drawer secured to the undersurface of said member in such fashion as to be movable completely beneath said member and movable outwardly relative to said member for rendering the contents of said drawer accessible.

Notes About Inventions and Inventors



On this and the following pages are listed some of the patents granted to General Motors prior to February 29, 1956. The brief patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each patent.

• **Kenneth P. Smith,** *Ternstedt Division, Detroit, Michigan, for an Automobile Door Lock, No. 2,723,145, issued November 8.* This patent relates to features of construction of the retractor and actuator mechanism in a pivot bolt door lock.

Mr. Smith has been contact engineer in quality control since 1953. He joined Ternstedt in 1937, and his subsequent work as an experimental design engineer on door locks resulted in a patent grant.

• **William E. Brown,** *Delco-Remy Division, Anderson, Indiana, for a Direction Signal Switch Mechanism, No. 2,724,750, issued November 22.* This patent relates to an improved, manually set, automatically cancelled direction signal switch operating mechanism.

• **William E. Brown,** *Delco-Remy Division, Anderson, Indiana, for an Electric Control, No. 2,724,758, issued November 22.* This patent relates to a specific form of switch for controlling block light circuits used on an experimental car.The switch includes a rotatable bridging contact and a series of fixed contacts engageable thereby, one of which controls the initial heating of the block light tubes.

• **William E. Brown,** *Delco-Remy Division, Anderson, Indiana, for a Switch, No. 2,725,432, issued November 29.* This invention relates to a switch which includes a spring which constantly urges the contact carrier toward a neutral position. The switch is used in antenna control apparatus.

• **William E. Brown,** *Delco-Remy Division, Anderson, Indiana, for an Electric Switch, No. 2,727,955, issued December 20.* This patent is directed to a type of switch used in a glove compartment wherein a reciprocating plunger operates the switch to open or closed circuit position with respect to the position of the plunger.

• **Harold V. Elliott,** *Delco-Remy Division, Anderson, Indiana, for a Directional Signal Switch, No. 2,733,309, issued January 31.* This patent relates to improvements in manually set, automatically reset signal operating mechanisms.

• **Harold V. Elliott, William E. Brown, and Harold F. Brown,** *Delco-Remy Division, Anderson, Indiana, for a Compartment Light and Switch, No. 2,734,992, issued February 14.* This invention relates to a glove compartment switch structure
which has a reflector providing a suppo
for the bulb socket and switch mech
anism. The reflector is arranged to dire
the light from the bulb in the glov
compartment.

Mr. William Brown has been sta
engineer in the Product Engineerin
Department since 1953. He joined Delc
Remy in 1925 as a high school co-o
student, then attended General Moto
Institute. His work has re ulted in t
grant of 21 patents on starter contro
lighting circuits, and generator regul
tion.

Mr. Elliott is a senior project enginee
having joined Delco-Remy in 1936 as
blueprint operator. He was graduate
from General Motors Institute in 193
As a result of his work on circuit breaker
ignition timers, and terminal switche
9 patents have issued.

Mr. Harold Brown is senior checker
the ignition section of the drafting roo
at Delco-Remy. He joined this Divisi
in 1942 as a General Motors Institu
co-op student and has since worked as
drafting apprentice and senior detaile

• **Robert T. Psik,** *Ternstedt Divisio
Detroit, Michigan, for a Push Button Do
Lock, No. 2,724,958, issued November 2*
This patent relates to a door handle pus
button assembly in which the pus
rod has oppositely-disposed wings whic
pass through an elongated slot when th
assembly is in unlocked position an
which may be rotated through an arc
90° so that the wings are blocked fro
passing through the slot when the assem
bly is in locked position.

Mr. Psik is a senior design engineer i
Product Engineering and Developmen

Contributed by

Patent Section

Central Office Staff

Continued from page 37

Infringement of Other Patents Should Be Investigated

Analyzing the 2 claims from the 2 patents, it is seen that the second inventor could not manufacture his improved table having a drawer under it without making a table meeting the description set forth in the claim of the first patentee. Furthermore, the first patentee cannot manufacture the new table with the drawer without infringing the claim of the second patent. The second patentee could exclude everyone else from manufacturing his improved table but still was not free to manufacture it himself until the first patent expired. In this situation a license from the first patentee would permit the second patentee to make the new table, or cross licenses between the patentees would make it possible for each to make the improved article.

The courts in passing on patents have construed the provision of the statute which formerly granted to the patentee the exclusive right to make, use, and sell his invention, as actually conferring upon him the right to exclude others from making, using, or selling the invention. This construction by the courts has now been incorporated in the patent statutes so that patents now clearly state that the inventor is granted only the right to exclude others from making, using, or selling the invention.

having joined Ternstedt in 1936, then a subsidiary of Fisher Body. He is currently working on door and rear compartment lid hinges. He was granted the B.S.M.E. in 1935 from Michigan State University.

• **Francis F. Trittschuh,** *Aeroproducts Operations, Allison Division, Dayton, Ohio, for a Dehumidifier Control System, No. 2,725,196, issued November 29.* This invention relates to a control system for a dehumidifier including means for effecting periodic operation of the dehumidifier for a predetermined time interval and means responsive to the amount of moisture condensation collected during the interval for continuing or discontinuing operation of the dehumidifier dependent upon the amount of condensate collected during the interval.

Mr. Trittschuh, as experimental engineer at Aeroproducts Operations, deals with turbo-prop testing and test house operations. He joined Allison in 1941 as a test operator, and his work on control systems has resulted in 1 patent grant.

• **Frank J. Winchell** (*now at Chevrolet Motor Division*), *Cadillac Cleveland Tank Plant, Cleveland, Ohio, for a Bearing Construction, No. 2,726,906, issued December 13.* This patent deals with a bearing construction for large-diameter bearings with ball bearings at spaced intervals about the race and load relieving means.

Mr. Winchell is assistant staff engineer, having joined Chevrolet in 1952. His work concerns automatic transmissions. After attending Purdue University, he joined Allison Division, transferring to Cadillac's Cleveland Tank Plant as assistant staff engineer in 1951.

• **Leroy W. Shutts,** *Allison Division, Indianapolis, Indiana, for Pivoted Vane, No. 2,728,354, issued December 27.* This patent relates to an actuating mechanism for positioning a highly loaded, pivotable deflector vane without the transmission of turning force at the pivotal axis of the vane.

Mr. Shutts, a product engineer, is currently working on the development of the T-56 turbo-prop aircraft engine combustion chamber. He has over 30 years' experience as project engineer with GM Research Staff and since 1941 with Allison. Five patents have issued as a result of his work.

• **Clarence J. Tobin,** *GM Research Staff, Detroit, Michigan, for a Process of Making Zinc Base Alloys, No. 2,728,657, issued December 27.* This invention relates to a process of making a drawing die of a highly wear-resistant zinc-base alloy containing specified amounts of aluminum, copper, magnesium and dispersed, hard particles of an intermetallic compound of manganese and silicon.

Mr. Tobin is an assistant head of the Metallurgical Engineering Department. He received the B.S. in chemical engineering in 1920 from University of Michigan and joined the Research Staff in 1925 as a metallographer. His work has resulted in 2 patents.

• **William J. Adams,** *Euclid Division, Cleveland, Ohio, for a Tapered Cutting Edge for Digging and Carrying Scraper and Associated Apron, No. 2,729,001, issued January 3.* This patent relates to improvements in scraper bowl construction for an earth-digging and -carrying vehicle.

Mr. Adams is senior development engineer and consultant in the Product Engineering Department. He joined Euclid in 1947, where his contributions to self-loading earth-moving machinery have included the Euclid 4-wheel drive scrapers and rubber-tired tractors to pull them.

• **Edwin S. Dybvig,** *Frigidaire Division, Dayton, Ohio, for a Refrigerating Apparatus Having Reheating Means, No. 2,729,072, issued January 3.* In this patent the condenser and evaporator are connected to the remainder of the refrigerating system by flexible tubing. Both the condenser and the evaporator are laterally shiftable to present all or a part of each into either the cooling or heat-rejecting air streams, providing either normal or reversed-cycle refrigeration and adjustable reheating.

Mr. Dybvig is a patent attorney in the Dayton Office of the GM Patent Section. He received the B.E.E. in 1929 from the University of Minnesota and the LL.B. in 1933 from Washington College of Law.

***Inventors' names marked with an asterisk in this section have had their biographies published in a previous issue of Volume 3, GENERAL MOTORS ENGINEERING JOURNAL**

As a result of his work on air conditioning 5 patents have issued.

• **William Smith, Jr.,** *Frigidaire Division, Dayton, Ohio, for a Dishwashing Machine, No. 2,729,219, issued January 3.* In this patent the dishwasher has its bottom outlet connecting directly with the top inlet of a garbage disposer so that dishes may be placed in the dishwasher without being scraped. The food wastes on the dishes will be carried by the initial flushing into the disposer, ground, and conducted to a drain.

Mr. Smith has been section head of the Appliance Engineering Department since 1947. He joined Frigidaire in 1936, and 2 patents have issued from his work in domestic appliances. He received the B.S. in chemistry and physics from Pennsylvania State University in 1927.

• **Robert O. Morgann and Russell J. Bush,** *Inland Manufacturing Division, Dayton, Ohio, for a Window Sealing Strip, No. 2,729,315, issued January 3.* The patent claims a sealing strip for sash-type windows wherein a length of elastomeric material having a flexible lip thereon is stretched around the periphery of the window with the lip extending beyond the frame. When the casement window is closed, the lip engages the portion thereof to seal around the window. The rubber sealing strip is engaged to the frame by means of hooks at either end thereof.

• **Russell J. Bush and Cletus L. Moorman,** *Inland Manufacturing Division, Dayton, Ohio, for a Sealing Strip, No. 2,736,076, issued February 28.* This patent relates to a sealing strip for use on refrigerator doors and the like, having a plurality of spaced bulb-like members integrally formed with a base which form a plurality of confined air spaces when deformed in the direction of the base.

Mr. Bush has been a project engineer since 1943, working on development of seals for curtain wall construction. He received the B.S. in chemical engineering from Purdue University in 1925. His work has resulted in 25 patent grants in refrigeration and rubber plant equipment.

Mr. Moorman has been a project engineer at Inland since 1953 and currently supervises the design of rotating shaft oil and grease seals. He joined Inland in 1939 and has worked on the design and development of hydraulic shock absorbers and power equipment. He attended the University of Dayton.

Mr. **Morgann** is no longer with the Division.

• **Philip J. Berner and James D. Connell,** *Inland Manufacturing Division, Dayton, Ohio, for a Switch, No. 2,729,713, issued January 3.* This invention is directed to a horn button assembly wherein simplified construction reduces the cost of the device while simultaneously providing good horn-blowing mechanism. The assembly includes a Belleville spring and may be locked in place within a steering wheel hub by use of the single nut used in connection with the wheel.

• **Philip J. Berner and James D. Connell,** *Inland Manufacturing Division, Dayton, Ohio, for an Attachment Device, No. 2,732,448, issued January 24.* This patent is for a spring clip attaching means for use in holding a cap on the top of a steering wheel column. The clip is provided with barbs on a circular base portion thereof which barbs bite into the wall of an opening in a cap member or the like when the base portion is driven therein to lock automatically the clip to the member.

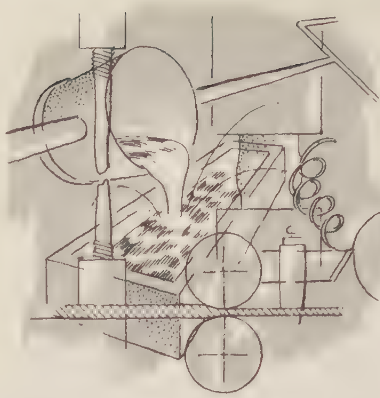
Mr. **Berner** has been a project engineer in the Engineering Department since 1945, having joined Inland as a design engineer in 1942. He received the M.E. degree from Stevens Institute of Technology in 1927 and is a registered professional engineer in the State of Ohio.

Mr. **Connell** has been a senior layout engineer since he joined Inland in 1951. His previous work has been in tool design and engineering. These are the first patents granted as the result of his work.

• **Floyd G. Dougherty, John B. Wheatley, and Charles J. McDowall***, *Allison Division, Indianapolis, Indiana, for a Combustion Chamber Crossover Tube, No. 2,729,938, issued January 10.* This patent relates to a crossover tube connecting flame tubes in a "cannular" gas turbine combustion apparatus for flame propagation between adjacent flame tubes.

Mr. **Dougherty** is chief of the aircraft gas turbine combustion group. He was granted the B.S.M.E. degree in 1939 from Purdue University and became a test engineer at Allison in 1940. Two patent grants have resulted from his work on gas turbine combustor design.

Mr. **Wheatley** has been assistant chief engineer since 1951. He joined Fisher Body in 1943 as an aeronautical engineer,



transferring to Allison in 1945. He received the A.B. in mechanical engineering (1929) and the M.E. in aeronautics (1930) at Stanford University.

• **Herman A. Brohn,** *Buick Motor Division, Flint, Michigan, for a Crankcase Ventilation System, No. 2,730,086, issued January 10.* This invention involves a novel crankcase ventilation system especially applicable for V-type engines in which a middle partition is provided across the camshaft gallery and the crankcase to provide air circulation downwardly on one side of the partition and upwardly on the opposite side of the partition.

Mr. **Brohn** is chief draftsman of Buick's special projects division. He joined Buick in 1919. His work has included drafting in the designs of the current Buick V-8 and the XP-300 and Le Sabre engines.

• **Gilbert Burrell,** *Oldsmobile Division, Lansing, Michigan, for an Intake Manifold, No. 2,730,091, issued January 10.* This patent relates to an intake manifold for a pair of 4-barrel carburetors in which the various distribution passages are arranged in a novel manner to provide each of the cylinders with identical charges.

Mr. **Burrell** has served as motor engineer in the Product Engineering Department since 1946. He joined Oldsmobile in 1928 as a dynamometer operator after receiving the electrical engineering degree from Michigan State University.

• **Russell S. Thatcher and Roy L. Bowers,** *AC Spark Plug Division, Flint, Michigan, for a Filter Valve with Deflector, No. 2,730,-125, issued January 10.* This invention relates to a relief valve in which a spring determines the opening of the valve and exerts a lateral thrust on the valve head by means of an eccentric washer in order to dampen vibration which heretofore arose because of fluid forces.

Mr. **Bowers** is staff engineer in the Engineering Department, where he began his career in 1932 as a draftsman. He was granted the B.S. degree in 1930 from Michigan State University. Four previous patents cover fuel pumps and filter valves.

Mr. **Thatcher** is no longer with the Division.

• **Milton H. Bennert,** *Process Development Staff, Detroit, Michigan, for a Process of Electrolytic Deburring of Metal, No. 2,730,-494, issued January 10.* This patent discloses a 2-step electrolytic method for removing burrs from ferrous metal and forming a clean, bright surface. The work is first made the anode in an electrolyte of hydrochloric acid and water to remove the burrs. This leaves a smudge which is then removed by anodic treatment in a solution containing phosphoric acid and water or containing phosphoric acid, hydrochloric acid, and water.

Mr. **Bennert** is senior chemical engineer in the Process Development Section, having been with this Section since his transfer from Fisher Body in 1947. He received the B.A. (1940) and M.A. (1941) from Albion College. His work concerns plastics and spectrographic techniques.

• **Albert D. Baker, Kenneth L. Jones, and Ernest A. Leavengood,** *Oldsmobile Division, Lansing, Michigan, for a Refrigerating Apparatus, No. 2,730,866, issued January 17.* This invention relates to an automobile air conditioning system and various features thereof, such as the ducts used for directing the conditioned air into the passenger compartment of a car.

• **Albert D. Baker** (*Oldsmobile Division*), **Lloyd E. Muller** (*Buick Motor Division*), and **Edward P. Harris***, *Inland Manufacturing Division, Dayton, Ohio, for an Air Grille, No. 2,731,104, issued January 17.* This invention relates to an air grille for use in automotive air conditioning systems. The grille is raised so that a package will not completely close the grille openings when the package is laid thereon. The grille frame includes means for supporting an air filter therein.

Mr. **Baker** is heating, cooling, and ventilating engineer in Oldsmobile's Product Engineering Department. After receiving the B.S.M.E. in 1926 from Purdue University, he joined the GM

Research Staff. He transferred to Oldsmobile in 1930.

Mr. Jones is a senior project engineer. He joined Oldsmobile as a laboratory technician in 1935 after receiving the degree in electrical engineering from the International School of Correspondence.

Mr. Leavengood is head of the Electrical Section in the Engineering Department of Oldsmobile. He joined this Division in 1929 at the GM Proving Ground after receiving the B.S. degree in physics from Michigan State University.

Mr. Muller has been staff engineer in charge of acoustics and vibration at Buick since 1939. He joined Buick in 1929 after receiving the B.S.M.E. from University of Kansas. Four patents have been issued as the result of his work on mufflers and air conditioning.

• **Charles W. Gadd**, *GM Research Staff, Detroit, Michigan, for a Displacement Pickup Device, No. 2,730,895, issued January 17.* This patent relates to a displacement-type pickup device unaffected by spurious resonances and high temperature effects otherwise causing inaccuracies in measuring high-frequency vibrational deflections.

Mr. Gadd has been supervisor of vibration and stress analysis in the Special Problems Department since 1953. After receiving the B.S.M.E. degree from Massachusetts Institute of Technology in 1937, he joined the Research Staff as a junior engineer.

• **Clarence R. Lunn**, *Rochester Products Division, Rochester, New York, for a Carburetor Venting Device, No. 2,731,251, issued January 17.* The device of this patent is a carburetor, and invention lies in provision of a plurality of vent tubes which can be adjusted to control mixture ratio by slightly varying pressure in fuel chamber and can be set to remove vapor from space above fuel. Tubes are press-fitted and can be adjusted after the carburetor is assembled to give required mixture ratio under different operating conditions.

Mr. Lunn has served as supervisor of Michigan area sales engineers for Rochester Products since 1949. He has a background of 27 years in carburetor developmental work related to automobiles, trucks, and military vehicles, having joined GM in 1929.

• **Kai H. Hansen** (*now at Chevrolet Motor Division*), *Cadillac Motor Car Division, Detroit, Michigan, for Independent Vehicle Wheel Suspensions, No. 2,731,257, issued January 17.* This patent relates to an independent wheel suspension in which the torsional stabilizer and shock absorber are so arranged as to reduce torsional stresses on the associated wishbone arm.

Mr. Hansen is an assistant staff engineer working on truck research and development at Chevrolet. After attending Lawrence Institute of Technology, he joined Fisher Body in 1939. His work has concerned suspensions and power steering at Cadillac and Chevrolet.

• **David C. Redick**, *Delco-Remy Division, Anderson, Indiana, for a Direction Signaling Device, No. 2,731,525, issued January 17.* This patent relates to improvements in direction signal switch mechanisms.

Mr. Redick is section head of switches and horns, having joined Delco-Remy in 1936. He is a 1939 graduate of General Motors Institute. Two patents in the field of switches have issued as the result of his work.

• **Harry C. Doane** (*now at GM Engineering Staff*), *Buick Motor Division, Flint, Michigan, for an Electric Connector, No. 2,731,617, issued January 17.* The channel-shaped terminal shown in this patent has inwardly curled flanges forming a stop for the spring tongue. The cooperating, removable blade slides in between the spring tongue and the terminal and has an aperture which registers with and receives a rounded projection upon the spring tongue to form a resilient lock.

Mr. Doane was appointed assistant to C. A. Chayne, vice president in charge of Engineering Staff, in June 1956. He had been assistant chief engineer at Buick since 1949, having joined Buick in 1924. His work in the fields of mechanical and electrical engineering has resulted in 22 granted patents.

• **Joseph H. Overwein, Raymond C. Davis, and Murray S. Millhouse**, *Inland Manufacturing Division, Dayton, Ohio, for a Method of Forming an Ornamental Plastic Article, No. 2,731,672, issued January 24.* This invention relates to a method for forming a laminated plastic part having an ornamental design carried by one of the layers or partially carried by each of 2 layers. The design, when viewed through a smooth surface of the part, appears in raised relief within the article.

Mr. Overwein has served as supervisor of the Plastics Laboratory since 1950. His work concerns crash pads and automotive suspension parts. He joined Inland in 1943 after receiving the bachelor degree in chemical engineering from University of Dayton.

Mr. Davis has been assistant to the chief engineer since 1942, having joined Inland as a design engineer in 1931. He was granted the degree in mechanical engineering in 1920 from Dayton Night College.

Mr. Millhouse has been project engineer since 1953, working with polyurethane foam mixing units, plastics, and rubber extrusions. He joined Inland in 1936 and received the diploma in industrial engineering from General Motors Institute in 1941.

• **Albert J. Kuhn**, *Frigidaire Division, Dayton, Ohio, for a Refrigerating Apparatus, No. 2,731,805, issued January 24.* This invention relates to an automobile air conditioning system wherein a rheostat controls the amount of heat applied to a thermostat which, in turn, controls the bypassing of refrigerant from the outlet of the refrigerant condenser to the inlet of the compressor.

Mr. Kuhn is senior project engineer in the Household Engineering Department. He earned the B.S.E.E. from University of Dayton in 1930. His work concerns railway air conditioning, Diesel power units, and freight car refrigeration.

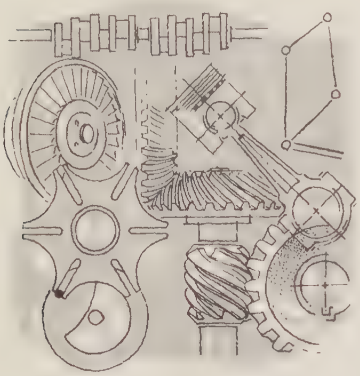
• **Frederick W. Sampson** (*now at Moraine Products Division*), *Inland Manufacturing Division, Dayton, Ohio, for a Universal Joint, No. 2,731,813, issued January 24.* This patent is directed to a universal joint wherein the inner and outer spherical segments thereof include a resilient intermediate elastomeric segment bonded to each and held in a state of compression. The elastomeric material acts as a driving means and also a shock absorbing medium.

Mr. Sampson was chief engineer from 1942 to 1956, having joined Inland as assistant chief engineer in 1929. In 1956 he was made section engineer on special assignment at Moraine. He received the

These patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each one.

M.E. from Cornell University in 1924. More than 40 patents have been issued as a result of his work on automotive parts and firearms.

• **Salvatore F. Marino,** *New Departure Division, Bristol, Connecticut, for a Driving Mechanism for Cycles, No. 2,731,857, issued January 24.* This patent relates to a selective, 3-speed driving hub for a



bicycle. The speed may be manually preselected and a subsequent shifting of the gear will occur when there is a change in torque load in the drive.

Mr. Marino is a senior engineer, working on special assignments in research and development. He received the B.S.M.E. from Worcester Polytechnic Institute in 1928 and joined New Departure in 1935. Patents on anti-friction bearings and bicycle brakes have issued from his work.

• **Holle C. Luechauer,** *Moraine Products Division, Dayton, Ohio, for an Exciter Stand for Spectrograph, No. 2,731,876, issued January 24.* This invention relates to an exciter stand for a spectroscope. The stand is arranged to maintain a flat or curved surface at a predetermined distance from the sparking electrode of the spectroscope.

Mr. Luechauer is senior experimental chemist. His work entails supervision of the Chemical, Plating, Infrared, and Emission Spectrographic Laboratories. He received the A.B. degree from University of Cincinnati in 1927 and joined Moraine Products in 1949.

• **Edward Orent and Stuart F. Kutsche,** *Diesel Equipment Division, Grand Rapids, Michigan, for an Engine Fuel System, No. 2,731,976, issued January 24.* This patent relates to a device for dividing flow between the small-flow and large-flow ports of duplex gas turbine fuel nozzles. Pressure drop through an orifice due to flow to the small-flow nozzle ports lifts a piston against a spring, concurrently opening throttle valves individual to the large-flow line of each nozzle.

Mr. Orent has been superintendent of Diesel and aircraft activities since 1955, having joined Diesel Equipment in 1945 as a design checker. He received the B.S.M.E. degree from University of Michigan in 1944.

Mr. Kutsche has been a senior project engineer since 1953, and his work applies to fuel nozzle development. He was granted the B.S.M.E. in 1943 from Georgia Institute of Technology and joined the Division in 1948 as a layout draftsman.

• **Elmer Olson, J. Martin Kelly** (*now at AC Spark Plug Division*), **George L. Gibbs, Jr., and Erwin J. Reppert,** *Rochester Products Division, Rochester, New York, for an Anti-Stall Device, No. 2,732,038, issued January 24.* This patent is directed to an air dash pot for retarding the closing movement of the throttle when accelerator pedal is released, to prevent possible stalling.

• **Erwin J. Reppert and J. Martin Kelly,** *Rochester Products Division, Rochester, New York, for a Throttle Return Check, No. 2,735,643, issued February 21.* This patent is for a dash pot eliminating a separate valve to retard closing movements of a carburetor throttle valve through an arm controlled by a diaphragm acting as a valve itself to block air flow through openings as a diaphragm surface engages a raised surface on an arm-connected disc in the dash pot, retarding action in one direction of movement with free passage of air occurring for unretarded action in the opposite direction.

Mr. Olson has been chief engineer since he joined this Division in 1945. He is concerned with studies on carburetion and fuel handling devices. He attended the Lewis Institute in Chicago and has a background of 20 years in carburetor developmental work.

Mr. Kelly has been a senior product engineer at AC since 1955. After receiving the B.S.E.E. degree from Carnegie Institute of Technology in 1925, he joined Delco-Remy as a junior engineer. His GM career also includes work at Delco Products, Delco Brake, and Rochester Products Divisions.

Mr. Gibbs has been supervisor of production drafting since 1954, having joined Rochester Products as an assembly inspector in 1941. His present work entails the training of new draftsmen.

Mr. Reppert has served as senior project engineer since 1952, dealing with standards engineering work in the field of carburetors and fuel pumps. He joined Rochester Products in 1939 after receiving the B.S. degree from Cornell University.

Rolf M. Smith (*now at Allison Division*), *Frigidaire Division, Dayton, Ohio, for a Refrigerating Apparatus, No. 2,732,120, issued January 24.* This patent discloses a rotary, eccentric type of compressor having 2 diametrically opposite vanes. The side walls have wedge-shaped ports providing high-capacity for each suction chamber.

Mr. Smith, as senior project engineer, works on controls for turbo-prop and jet engines. He joined Frigidaire in 1929, transferring to Allison in 1955. He was granted the M.E. degree from University of Minnesota in 1929. His work in refrigeration has resulted in 13 patents.

• **George B. Long,** *Frigidaire Division, Dayton, Ohio, for a Garbage Disposal Device, No. 2,732,135, issued January 24.* The disposer in this patent has an annular trough beneath the impeller which collects any water flowing through the disposer. Pivoted on a radius to the impeller are 2 vanes which dip into the trough so that when water flows and the impeller rotates the reaction with the water in the trough will lift the vanes to grind the garbage.

Mr. Long is supervisor of major products line in the Research and Future Products Engineering Department, where his work concerns kitchen planning, major component and accessory research and development. He received the B.S.E.E. degree in 1937 from Purdue University.

• **William K. Schnepf,** *Delco Appliance Division, Rochester, New York, for a Motor Control Means, No. 2,732,523, issued January 24.* This invention relates to a control system for an electric windshield wiper motor, including electromagnetic means responsive to motor current for modifying the operation of an automatic parking switch so that the motor will always have sufficient coast inertia after de-energization to park the wiper blades driven thereby.

Mr. Schnepf has been a developmen

engineer since he joined Delco Appliance in 1950. His work has included the design of windshield wipers, electrical controls, and electronic devices. This work has resulted in 4 granted patents.

• **Charles A. Chayne*** (*now at GM Engineering Staff*), *Buick Motor Division, Flint, Michigan, for a Wheel Suspension Comprising Sectional Dead Axle and Connections Therefrom to Vehicle Frame, No. 2,732,903, issued January 31.* This patent concerns an independent rear wheel suspension in which the wheels are aligned by a sectional dead axle, each part of which is capable of limited rotation.

• **Charles A. Chayne*** (*now at GM Engineering Staff*), *Buick Motor Division, Flint, Michigan, for a Cylinder Block, No. 2,734,497, issued February 14.* This patent relates to cylinders that project into the crankcase beyond the cooling liquid jackets and walls supporting the crankshaft bearings that are cut away opposite the ends of the cylinders so that the cylinder ends may be of uniform thickness and will not distort out of cylindrical form. The block also has reinforcing columns between the front and rear walls and integrally with respect to the inner cooling liquid jacket walls.

• **Ralph R. Anderson and William T. Gerber,** *Cadillac Motor Car Division, Detroit, Michigan, for a Transmission Control Indicator, No. 2,732,905, issued January 31.* This patent relates to a transmission control indicator structure wherein the indicator needle is located adjacent the principal instrument cluster.

Mr. Anderson has been design group leader in the Engineering Department since 1952. After attending the School of the Art Institute of Chicago and Wayne State University, he joined the GM Styling Section in 1939, transferring to Cadillac in 1942 to work on heating and air conditioning.

Mr. Gerber is a senior designer on body components in the Engineering Department. He is a graduate of the DeSmet Body Course. He joined Cadillac in 1937 and advanced through the positions of detailer, senior detailer, and layout draftsman to his present position.

• **Robert N. Falge,** *Guide Lamp Division, Anderson, Indiana, for a Headlamp Adjusting Device, No. 2,733,335, issued January 31.* This patent relates to an improvement in an adjustable automobile headlamp mounting which allows for easier adjustment without binding by the provision of adjustment nuts designed to be rockable in their mountings.

Mr. Falge has served as chief engineer at Guide Lamp since 1937, having joined the GM Research Staff in 1927. He received the electrical engineering degree in 1916 from University of Wisconsin. He serves on a number of industry committees on vehicle lighting.

• **David P. Clayton,** *Guide Lamp Division, Anderson, Indiana, for a Fastening Device, No. 2,733,336, issued January 31.* This patent relates to a headlamp mounting utilizing wire clips of an improved design which allows them to be used for various size lamps, thereby resulting in greater standardization and lower cost of manufacture.

Mr. Clayton has served as junior designer in the Engineering Department since 1951. He joined Guide Lamp in 1939 as a paint rack repairman and has worked as model-shop crib attendant, apprentice model maker, model maker, and draftsman.

• **Wilfred A. Bychinsky,** *AC Spark Plug Division, Flint, Michigan, for Igniter Plugs, No. 2,733,385, issued January 31.* This patent concerns the construction of a jet engine igniter plug to provide for the use of higher voltages without any substantial increase in the amount of insulation and improved air cooling of the electrodes and electrode supporting structure.

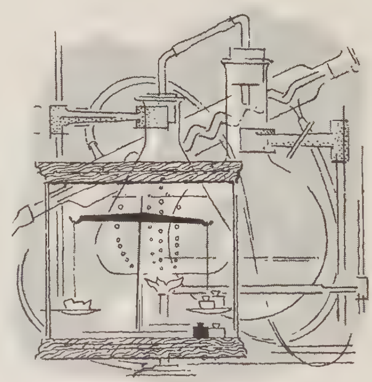
• **Wilfred A. Bychinsky,** *AC Spark Plug Division, Flint, Michigan, for a Spark Plug Terminal, No. 2,736,877, issued February 28.* This patent covers a spark plug having an electrical terminal formed with an upper contoured portion and a lower contoured portion which are joined by a frangible section so that the upper contoured portion can be easily broken off to reduce the length of the spark plug.

Dr. Bychinsky is assistant chief engineer, motor group, at AC, having joined the Division in 1933. His work has resulted in 10 granted patents. He was awarded the B.S.E.E. in 1930, the M.S.E. in 1931, and the Ph. D. degree in 1933 from the University of Michigan.

• **Harold W. Schultz,** *Moraine Products Division, Dayton, Ohio, for a Method of Making Bearings, No. 2,734,024, issued February 7.* This patent is directed to a method of co-depositing a lead-base alloy to the surface of an aluminum bearing in specific and critical thicknesses not in excess of 0.001 in.

Mr. Schultz has been section engineer at Moraine Products since 1952 and a member of the Engineering Department since 1937. His work on friction materials, aluminum cladding to steel, plating, and adhesives has resulted in 11 granted patents.

• **Howard W. Christenson,** *Allison Division, Indianapolis, Indiana, for a Torque Converter Drive, No. 2,734,399, issued February 14.* This invention relates to a particular arrangement of hydraulic torque converter, which can be short circuited by a lock-up clutch, driving a compound planetary gear and an associated control system arranged to provide a low range of speed ratio changes, both in forward drive and in reverse, and a higher range of speed ratio changes in forward. A manual



control can be set to limit the speed changes to the lower range or to permit them to change automatically throughout the entire range, including the high range.

Mr. Christenson has been chief engineer of transmission research and development since 1953. Receiving the B.S. degree in 1938 from Oregon State College, he joined GM Research Staff, transferring to Allison in 1947. His work on hydraulic transmissions has resulted in 3 patent grants.

• **Carel F. Abresch and Francis H. McCormick,** *Frigidaire Division, Dayton, Ohio, for a Dishwashing Machine No. 2,734,520, issued February 14.* This invention relates to a dishwashing machine

having a horizontally-disposed rotatable spray tube and having a slidable dish-supporting rack extending above and on opposite sides of the spray tube.

Mr. Abresch has been senior project engineer in Frigidaire's Appliance Engineering Department since 1948. He attended the Institute of Technology in the Netherlands. His work on household appliances has resulted in 7 patents.

Mr. McCormick has been assistant chief engineer since 1942, having joined Frigidaire in 1936. His work on the design of ranges, washers, and other appliances has resulted in more than 40 patents. He received the B.S.E.E. from Washington State College in 1915.

• **John M. Wiggans,** *Allison Division, Indianapolis, Indiana, for a Protective Filtering System, No. 2,734,523, issued February 14.* This invention provides a means for maintaining a finely filtered flow of fluid between relatively movable valve members so that the valve members can control dirty fluid without sticking or seizure.

Mr. Wiggans has been section chief of turbo-jet controls since 1953, where he is responsible for design and development of turbo-jet controls for current production and future models. He received the B.S.M.E. from Purdue University in 1939, joining Allison in 1941.

• **John T. Rausch,** *Chevrolet Motor Division, Detroit, Michigan, for an Air Flow Control Means, No. 2,734,525, issued February 14.* This patent relates to a crankcase ventilating valve means, providing flow restriction and relief dependent upon and proportionate to flow pressure within the ventilating system.

Mr. Rausch, as staff engineer at Chevrolet Engineering Center, coordinates forward planning of engine design and development. He joined Chevrolet in 1930 as a General Motors Institute co-op student, graduating in 1933. Working at Chevrolet until 1940, he transferred to Allison to do product design and quality control. He returned to Chevrolet as a project engineer in 1946.

• **Lloyd T. Fuqua,** *Guide Lamp Division, Anderson, Indiana, for a Pre-Focus Type Light Bulb Mounting, No. 2,734,994, issued February 14.* This patent covers an improved pre-focus type lamp bulb mounting wherein a circular insulator ring around the base of the bulb carries 2 inwardly extending metal blades which establish electrical contact with the bulb.

Mr. Fuqua has been a senior designer in Guide Lamp's Engineering Department since 1950 and is currently working on non-glare mirrors and automotive lamps for future production. He attended DePauw University and joined Guide Lamp in 1941 as a detailer.

• **John B. Dyer and Raymond H. Sullivan,** *Delco Appliance Division, Rochester, New York, for a Motor Control Means, No. 2,735,029, issued February 14.* This patent is for an electric motor having a helically wound brake spring attached at one end to an armature shaft and engageable at its other end by an abutment pivotable into brake actuating position in response to the collapse of magnetic flux in a field coil of the motor for clutching, decelerating, and arresting rotation of the shaft, operative, for example, on a windshield wiper mechanism.

Mr. Sullivan serves as senior research engineer in Delco Appliance's Engineering Department, which he joined in 1912. His work involves the development of automotive electric clocks, motors, and oil burner controls.

Mr. Dyer is no longer with the Division.

• **Robert M. Tuck,** *Allison Division, Indianapolis, Indiana, for a Fluid Torque Converter Construction, No. 2,735,267, issued February 21.* This patent relates to an improved torque converter construction arranged to reduce the thrust loads on bearings employed in connection with the torque converter.

Mr. Tuck has been development engineer in the Transmission Engineering Department since 1953, having joined Allison in 1940 as a General Motors Institute co-op student. He was graduated from G.M.I. in 1944, receiving the B.M.E. degree from G.M.I. in 1947.

• **Leonard J. Mann*, John M. Murphy*, and Verlos G. Sharpe,** *Frigidaire Division, Dayton, Ohio, for a Refrigerating Apparatus with Air Baffle, No. 2,735,274, issued February 21.* This invention relates to a household refrigerator in which an air-deflector baffle prevents condensate formed on the evaporator from dripping onto food stored below the evaporator.

Mr. Sharpe is section engineer in the Household Engineering Department, having joined Frigidaire in 1948. He received the B.S.M.E. from Purdue University in 1948. Two patents have issued from his work on household refrigeratior

• **David C. Apps,** *GM Proving Grouna Milford, Michigan, for a Tire Thum Measuring Apparatus, No. 2,735,292, issue February 21.* The invention provides ap paratus for ascertaining the "thum number" of a tire by measuring th amplitude of the difference, or bea frequency, resulting from heterodynin of harmonic frequencies of tire rps pro duced by irregularities or discontinuitie in vehicle tires.

Mr. Apps has been head of the Nois and Vibration Laboratory at GM Prov ing Ground since 1945, having joinec this organization in 1934. He was grantec the B.S.E.E. from University of Michiga in 1934 and is a member of the S.A.E and the Acoustical Society of America

• **John Dickson,** *Detroit Diesel Engine Di vision, Detroit, Michigan, for a Follower No. 2,735,313, issued February 21.* Thi patent has to do with providing crownec cam engaging and journaling surfaces i a roller-type cam follower to accommo date slight misalignments in operation a might otherwise aggravate wear.

Mr. Dickson is in charge of forwarc design and development. He has beer associated with the design and manufac ture of Diesel engines for 35 years. As a result of his work 14 patents have issued He is a graduate of the Royal Technica College of Glasgow, Scotland.

• **Harold E. Schultze,** *Delco Products Divi sion, Dayton, Ohio, for a Self-Centering Shoc Absorber, No. 2,735,670, issued February 21* This patent is for a direct acting shoc absorber in which the piston is normall spring-retained in a mid position of it stroke and is movable in either directior from its mid position to effect shoc absorption, the piston returning to it mid position under action of the spring at the end of the shock action.

Mr. Schultze has been a project engi neer at Delco Products since 1954. H joined Delco in 1929, and his career ha centered around the design and develop ment of shock absorbers and hydrauli devices.

• **C.W. Lincoln,** *Saginaw Steering Gea Division, Saginaw, Michigan, for a Follow Up Mechanism, No. 2,736,208, issue February 28.* This invention relates to a mechanical servo adapted for use in th power steering of an automotive vehicle

The assemblage includes a pair of engine-driven, oppositely rotating members and corresponding clutches engaged and disengaged by means controlled by the turning of the steering shaft.

Mr. Lincoln is chief engineer, having joined the Division in 1932. The University of Illinois granted him the B.S.M.E. in 1916. His technical contributions include development of the recirculating ball steering gear and power steering for automotive vehicles.

• **Joseph May,** *Cleveland Diesel Engine Division, Cleveland, Ohio, for a Bolt Tensioner and Wrench, No. 2,736,219, issued February 28.* This patent relates to a tool for hydraulically applying a predetermined axial elongation to a bolt and including an improved wrench socket for tightening down a nut on the elongated bolt to eliminate the effects of friction inherent in torquing a nut on a bolt by conventional methods.

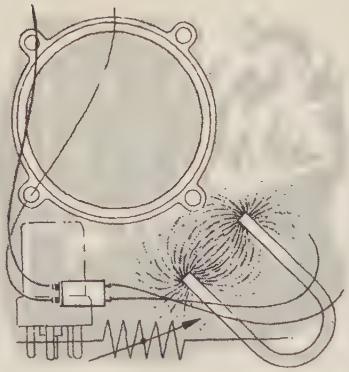
Mr. May is a project engineer working on combustion and air flow studies at Cleveland Diesel. He joined the Division in 1937 and has designed and built special hydraulic tools and assisted in developing a new method of installing slip rings on shafting for torsional and stress measurements.

• **Gregory Flynn, Jr.,** *GM Research Staff, Detroit, Michigan, for an Engine Cylinder Construction, No. 2,736,300, issued February 28.* This patent relates to a cylinder coolant jacketing arrangement for an engine, such as of the 2-stroke uni-flow scavenging type.

Mr. Flynn has served as assistant head of the Mechanical Development Department since 1953, working on development of free-piston, Diesel, and natural-gas engine design. Graduating from General Motors Institute in 1941, he became a junior engineer with the Research Staff.

• **James S. Burge, Floyd J. Foust, Hilton J. McKee, Warren M. Rider, and Willard C. Shaw*,** *Delco-Remy Division, Anderson, Indiana, for an Apparatus for Attaching a Terminal Clip to a Wire, No. 2,736,358, issued February 28.* This invention relates to a machine for automatically attaching terminal clips to the wire connector of an electrical condenser.

Mr. Foust has been inspection supervisor of machine tool and die design since 1950. He attended Purdue University and joined Delco-Remy in 1939 as an inspector. His present work is concerned with electronic equipment.



Mr. McKee serves as engineer in the Process Department, where he was employed in 1942. He is a 1932 graduate of Ball State Teachers College and has spent most of his career on the design of electrical machinery.

Mr. Burge is no longer with the Division.

Mr. Rider is no longer with the Division.

• **Olaf Rasmussen and Richard C. Rike,** *Moraine Products Division, Dayton, Ohio, for a Brake Slack Adjuster, No. 2,736,396, issued February 28.* This patent relates to an improved slack adjuster for hydraulic brakes having a ratchet mechanism located within the wheel cylinder to automatically adjust the piston position after each brake application to compensate for brake lining wear.

Mr. Rike is section engineer in charge of the brake engineering group at Moraine. He joined Delco Products in 1927 as a General Motors Institute co-op student, transferring in 1936 to Delco Brake (which became Moraine Products). His work in the field of brakes has resulted in several patent grants.

Mr. Rasmussen is no longer with the Division.

• **Paul E. Clingman,** *Inland Manufacturing Division, Dayton, Ohio, for a Sealing Strip, No. 2,736,404, issued February 28.* This invention is directed to sealing strips, for example, sealing strips for receiving windshields of automotive vehicles and the like, and is specifically concerned with a rubber-like sealing strip which includes a flexible channel therein for receiving the windshield. This permits considerable self-adjustment within the sealing strip for dimensional differences in the windshields.

Mr. Clingman has been supervisor of Quality and Control since 1953. He joined Inland in 1930 and earned the B.I.E. degree in 1935 from General Motors Institute. His work in the field of automotive bodies has resulted in several granted patents.

• **William G. Livezey,** *Allison Division, Indianapolis, Indiana, for Fluid Clutches with Multiple Pumps, No. 2,736,412, issued February 28.* This patent relates to the engine-driven pump and the output shaft-driven pump of an automatic transmission, which pumps are connected in series and have a pressure responsive bypass around each pump so that each pump forms the pressure-reducing means for the other, and the output shaft-driven pump is arranged to provide pressure when the vehicle is going in either direction.

Mr. Livezey has been chief designer in the Transmission Engineering Department since 1952, working on future transmission design studies. He joined Allison in 1936 and is a 1937 mechanical engineering graduate of the International School of Correspondence.

• **Ellwood F. Riesing,** *Inland Manufacturing Division, Dayton, Ohio, for a Fluid Seal, No. 2,736,584, issued February 28.* This patent relates to a fluid seal for use between relatively rotatable members which includes a pair of juxtaposed reinforcing rings disposed diagonally in the seal body and being capable of holding the seal within a housing.

• **Ellwood F. Riesing,** *Inland Manufacturing Division, Dayton, Ohio, for a Fluid Seal, No. 2,736,585, issued February 28.* This patent relates to a fluid seal for use between relatively rotatable members which includes a replaceable Teflon sealing lip portion.

• **Ellwood F. Riesing,** *Inland Manufacturing Division, Dayton, Ohio, for a Fluid Seal, No. 2,736,586, issued February 28.* This patent relates to a fluid seal for use between relatively rotatable members which includes a reinforcing member having annular spaced convolutes supporting the seal in a housing.

Mr. Riesing has been assistant chief engineer since 1954, having joined Inland in 1952. He is a member of the S.A.E., A.S.M.E., and the Engineering Society of Detroit. He is the author of several papers on rubber applications.

Solution to the Previous Problem:

Determine the Overall Length of a Rigid Tube Connecting 2 Points on a Gas Turbine Engine

By WILLIAM J. ELLIOTT
Allison Division
and ERIK H. HALVARSON
General Motors Institute

Tube length equals the sum of its straight elements plus the arc length of its bends

The design of rigid tubing used for fuel and oil system piping on gas turbine engines requires calculating the lengths of straight and curved sections of the tube, the tube's bending angles, and the angles of twist, or rotation, between section planes. The given data used to determine these various quantities, which are necessary to specify the tube's configuration in terms suitable for fabrication, are, first, the *xyz* coordinates of the tube's beginning and end points and its straight line intersections and, second, the bending radii. A useful mathematical tool for solving the complex geometrical problem presented in the design of such tubing is algebraic vector analysis. This is the solution to the problem presented in the July-August-September 1956 issue of the GENERAL MOTORS ENGINEERING JOURNAL in which the total length of tubing connecting 2 points on a gas turbine engine was to be determined. The total length as determined by the application of algebraic vector analysis is *11.359 in.*

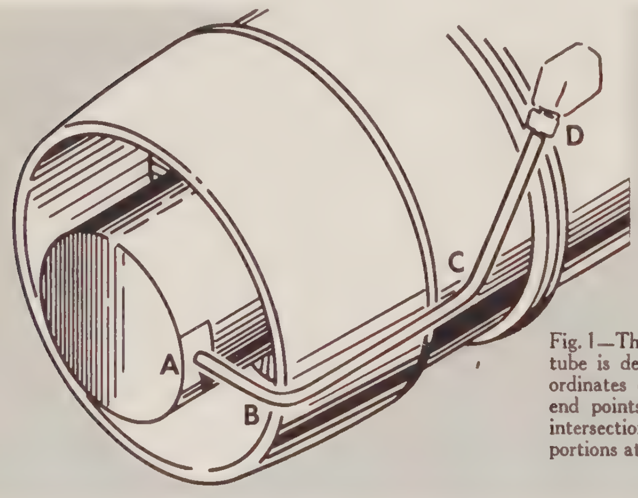


Fig. 1—The line path of the rigid tube is defined by the *xyz* coordinates of its beginning and end points *A* and *D* and the intersection of its straight portions at points *B* and *C*.

THE line path of the tube connecting the beginning and end points *A* and *D* respectively on a gas turbine engine with bends in the tube at points *B* and *C* (Fig. 1) was defined by the following *xyz* coordinates:

- Point *A* (0, 0, 0)
- Point *B* (0, −1, 2)
- Point *C* (5, −1, 2)
- Point *D* (7, 2, −1).

The portions of tubing between points *A* and *B*, points *B* and *C*, and points *C* and *D* may be represented by vectors **E**, **F**, and **G** respectively. Each of the 3 vectors, in turn, can be expressed in terms of its components, projected on the 3 axes of the *xyz* reference system, by the unit vectors **i**, **j**, and **k** which are associated with the *x*, *y*, and *z* axes respectively.

The components of each vector are stated in terms of its unit vectors **i**, **j**, and **k** as follows by using the *x*, *y*, and *z* coordinates which define the magnitude and direction of each vector:

$$\begin{aligned}\mathbf{E} &= (0-0)\mathbf{i}+(-1-0)\mathbf{j}+(2-0)\mathbf{k}\\ &= -\mathbf{j}+2\mathbf{k}\end{aligned}$$

$$\mathbf{F} = (5-0)\mathbf{i}+(-1-1)\mathbf{j}+(2-2)\mathbf{k}=5\mathbf{i}$$

$$\begin{aligned}\mathbf{G} &= (7-5)\mathbf{i}+(2+1)\mathbf{j}+(-1-2)\mathbf{k}\\ &= 2\mathbf{i}+3\mathbf{j}-3\mathbf{k}.\end{aligned}$$

The length of each of the vectors (vector length is designated in italics instead of boldface) can be calculated as follows:

$$E = \sqrt{(-1)^2+(2)^2} = \sqrt{5} = 2.236 \text{ in.}$$

$$F = \sqrt{(5)^2} = \sqrt{25} = 5.000 \text{ in.}$$

$$\begin{aligned}G &= \sqrt{(2)^2+(3)^2+(-3)^2}\\ &= \sqrt{22} = 4.690 \text{ in.}\end{aligned}$$

The angle between successive vectors **E** and **F** is called the bend angle α_1. This angle is determined by using the dot product and the following equation:

$$\mathbf{E}\cdot\mathbf{F} = EF\cos\alpha_1. \quad (1)$$

The dot between vectors **E** and **F** signifies that the product of **E** and **F** is to be a scalar product. The dot product of **E·F** can be calculated as follows by considering the *x*, *y*, and *z* coordinates of points *A*, *B*, and *C* to be $x_1y_1z_1$, $x_2y_2z_2$, and $x_3y_3z_3$ respectively:

$$\begin{aligned}\mathbf{E}\cdot\mathbf{F} &= (x_2-x_1)(x_3-x_2)+(y_2-y_1)(y_3-y_2)\\ &\quad+(z_2-z_1)(z_3-z_2)\end{aligned}$$

$$\begin{aligned}\mathbf{E}\cdot\mathbf{F} &= (0-0)(5-0)+(-1-0)(-1+1)\\ &\quad+(2-0)(2-2)\end{aligned}$$

$$\mathbf{E}\cdot\mathbf{F} = 0.$$

Substituting the value of the dot product **E·F** and the value of the lengths of vectors *E* and *F* into equation (1) gives the following value for the angle α_1 between vectors **E** and **F**:

$$\cos\alpha_1 = 0/(2.236)(5.000) = 0$$

$$\alpha_1 = 90°$$

In a like manner, the bend angle α_2 between vectors **F** and **G** can be calculated by using the dot product and the following equation:

$$\mathbf{F}\cdot\mathbf{G} = FG\cos\alpha_2 \quad (2)$$

The dot product of $\mathbf{F}\cdot\mathbf{G}$ can be calculated as follows by considering the x, y, and z coordinates of points B, C, and D to be $x_2y_2z_2$, $x_3y_3z_3$, and $x_4y_4z_4$ respectively:

$$\mathbf{F}\cdot\mathbf{G} = (x_3-x_2)(x_4-x_3)+(y_3-y_2)(y_4-y_3) + (z_3-z_2)(z_4-z_3)$$

$$\mathbf{F}\cdot\mathbf{G} = (5-0)(7-5)+(-1+1)(2+1) + (2-2)(-1-2)$$

$$\mathbf{F}\cdot\mathbf{G} = 10.$$

Substituting the value for the dot product $\mathbf{F}\cdot\mathbf{G}$ and the value for the lengths of vectors F and G into equation (2) gives the following value for the bend angle α_2:

$$\cos\alpha_2 = 10/(5.000)(4.690)$$

$$\alpha_2 = 64.76°.$$

Perpendicular to the plane formed by vectors **E** and **F** is a vector **H**. The value of vector **H**, in terms of its unit vectors **i**, **j**, and **k**, can be calculated as follows by taking the vector cross product of vectors **E** and **F** which formed the plane:

$$\mathbf{H}=\mathbf{E}\times\mathbf{F}=\begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 0 & -1 & 2 \\ 5 & 0 & 0 \end{vmatrix}=10\mathbf{j}+5\mathbf{k}.$$

The cross ($\times$) signifies that the product of **E** and **F** is a vector product.

Perpendicular to the plane formed by vectors **F** and **G** is a vector **I**. The value of vector **I**, in terms of its unit vectors **i**, **j**, and **k**, can be calculated as follows by taking the vector cross product of vectors **F** and **G** which formed the plane:

$$\mathbf{I} = \mathbf{F}\times\mathbf{G}=\begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 5 & 0 & 0 \\ 2 & 3 & -3 \end{vmatrix} = 15\mathbf{j} + 15\mathbf{k}.$$

The angle between vectors **H** and **I**, which are perpendicular to 2 adjacent planes, is the angle of rotation, or twist. This angle β_1 can be calculated by the following equation:

$$\cos\beta_1 = \mathbf{H}\cdot\mathbf{I}/HI \cdot (3)$$

The dot product of $\mathbf{H}\cdot\mathbf{I}$ is calculated in the same manner previously used for calculating the dot product $\mathbf{E}\cdot\mathbf{F}$. The dot product of $\mathbf{H}\cdot\mathbf{I}$ equals 225. The lengths of vectors H and I are 11.18 in. and 21.21 in. respectively. Substituting these values into equation (3) gives the following value for the angle of rotation β_1:

$$\cos\beta_1 = 225/(11.18)(21.21) = 0.040$$

$$\beta_1 = 18.435°.$$

The vector cross product of **H** and **I** yields a vector **L** which determines the direction of rotation. The value for vector **L** can be determined as follows:

$$\mathbf{L} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 0 & 10 & 15 \\ 0 & 15 & 15 \end{vmatrix} = 75\mathbf{i} = S\cdot\mathbf{F}$$

where

S = a scalar multiplier.

When the right hand rule is applied, it can be seen that, when S is negative, the vector **H** rotates counterclockwise into vector **I** and the angle of rotation is clockwise ($0° \leqq \beta_1 \leqq 180°$). When S is positive, the vector **H** rotates clockwise into vector **I** and a clockwise angle of rotation is given by $360° - \beta_1$. Since S is positive in regard to the tube under consideration the final angle of rotation is equal to $360° - 18.435°$, or $341.565°$.

The arc length of the tube's bends between vectors **E** and **F** and vectors **F** and **G**, a_1 and a_2 respectively, can be calculated as follows by multiplying the radius R, which equals 1 in. for each bend, by the bend angles α_1 and α_2 given in radians:

$$a_1 = R\alpha_1 = (1.000)(1.571) = 1.571 \text{ in.}$$

$$a_2 = R\alpha_2 = (1.000)(1.130) = 1.130 \text{ in.}$$

Between points A and B of the tube is a straight segmental length l_1 (Fig. 2). This length of tubing can be calculated by subtracting the length Δl_1 from the vectorial length E as follows:

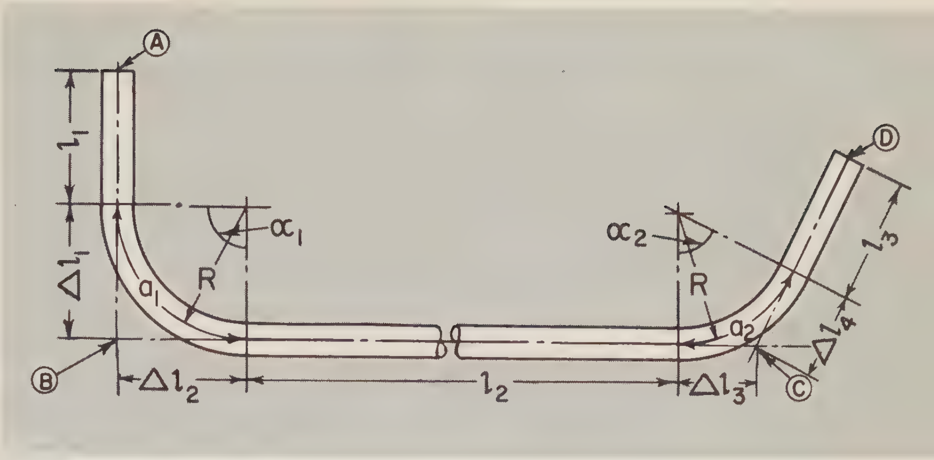


Fig. 2—The overall length of the tube is equal to the sum of its straight portions l_1, l_2, and l_3, between points A and B, B and C, and C and D respectively, plus the sum of the arc lengths a_1 and a_2 at points B and C. The individual arc lengths a_1 and a_2 are calculated by multiplying the radius R at each bend by the bend angles α_1 and α_2, in radians, at points B and C.

$$\Delta l_1 = (R)(\tan\alpha_1/2) = 1.000\ (\tan 45°) = 1.000 \text{ in.}$$

$$\Delta l_2 = \Delta l_1 = 1.000 \text{ in.}$$

The length Δl_3 can be calculated as follows:

$$\Delta l_3 = (R)(\tan\alpha_2/2) = 1.000(\tan 32.38°) = 0.634 \text{ in.}$$

$$\Delta l_4 = \Delta l_3 = 0.634 \text{ in.}$$

The segmental lengths of tubing l_2 between points B and C and l_3 between points C and D can be calculated as follows:

$$l_2 = F-\Delta l_2-\Delta l_3 = 5.000-1.000-0.634 = 3.366 \text{ in.}$$

$$l_3 = G-\Delta l_4 = 4.690-0.634 = 4.056 \text{ in.}$$

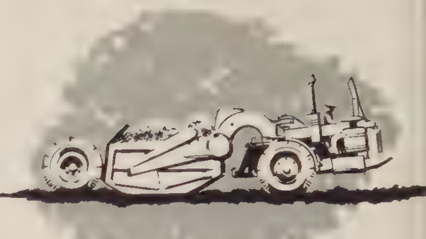
The total length of tubing required between the points A and D is equal to the sum of the segmental lengths l_1, l_2, and l_3 plus the sum of the arc lengths a_1 and a_2 or 1.236 in. +3.366 in. +4.056 in. +1.571 in. +1.130 in. equals 11.359 in.

Summary

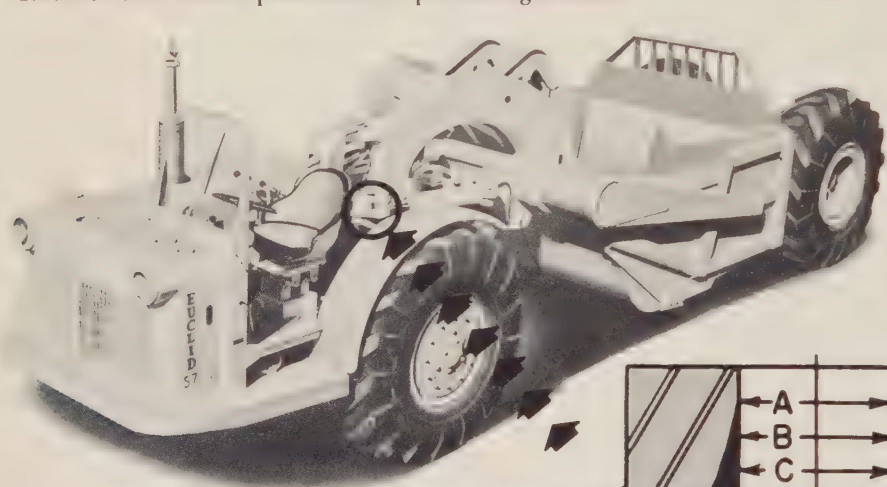
The method of employing vector analysis to determine the overall length of a tube can be used for any number of given coordinates. If calculations were started from the end of the tube instead of the beginning, as was done in this solution, the exact same results would be obtained. This procedure is used to check the results of the electronic calculators used by Allison Division for calculations relating to tubing layout work. Data are entered first in the given order and then in reverse order. The electronic calculator is programmed to compare automatically the 2 sets of results.

A Typical Problem in Engineering:

Determine the Diameter and Length of a Pin for a Pin-Bushing Type Joint by Bending Stress Evaluation



Earthmoving machinery utilizes a great number of pin-bushing type joints as an efficient, simple, and inexpensive method for connecting various mechanisms. The design of these pins ordinarily involves an accepted system of bearing and shear stress calculations for determining dimensions of pin diameter and bushing length. However, certain applications for the pin-bushing joints present wear problems which defy the standard method of design and require a further step in stress analysis. This procedure involves pin deflection or its related phenomenon of pin bending stresses.



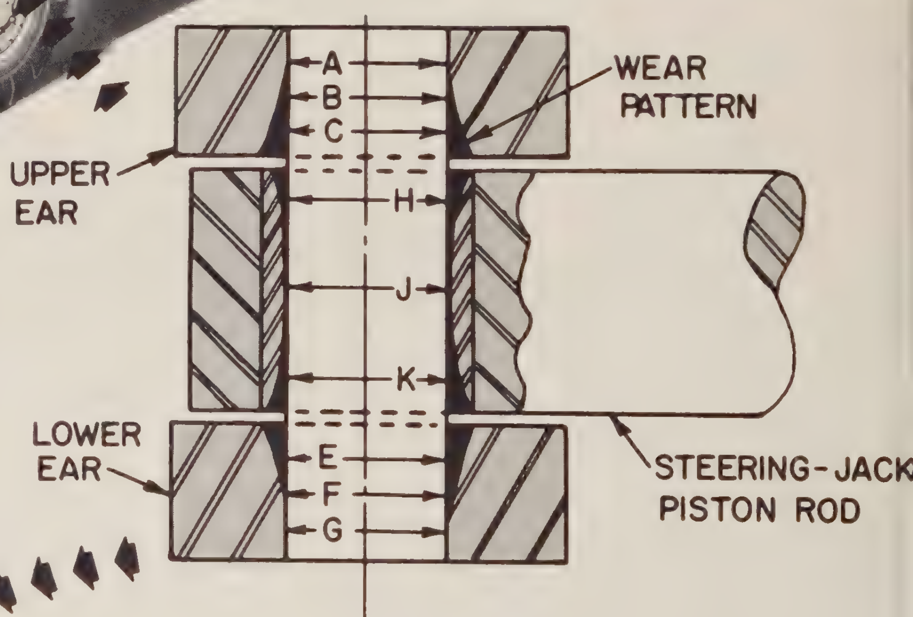
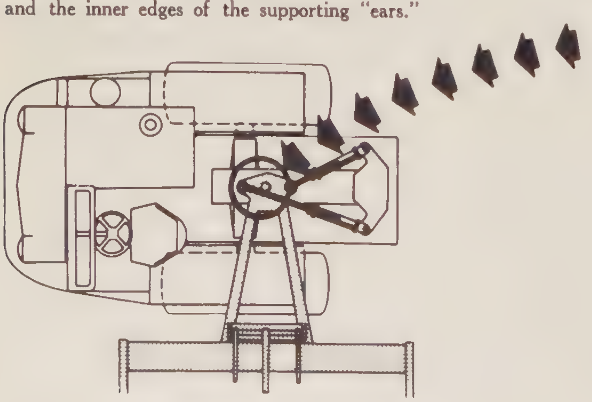
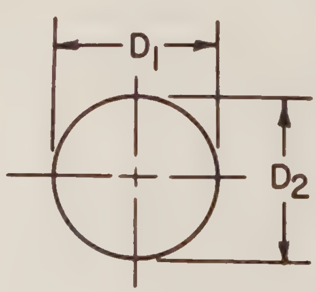


Fig. 1—The hydraulically operated steering-jack mechanism of the Euclid S-7 overhung-engine scraper is connected to the scraper drawbar by means of a pin-bushing type joint. The 2 hydraulic steering jacks are double acting and reversing and allow the scraper to turn through an arc of 90°, the position shown in the schematic plan view. The cross section of the steering-jack pin-joint connection indicates the wear pattern which resulted at the end of a 450-hr heavy-duty test performed during the early design stages of the S-7 scraper. The pattern indicated that the pin had deflected excessively and caused excessive bearing stresses on the outer edge of the bushing and the inner edges of the supporting "ears."





THE design of a pin joint can be re garded as a relatively simple matte —that is, when the working stresses fo both bearing and shear are known, th bushing pin sizes can be readily de termined. This practice has been followe through the years by designers and ha proven to be successful in most cases Actual experience with pin joints unde various loading applications, howeve indicates that there are other factor which must be considered. To illustrat

By BENJAMIN A. SLUPEK
and FRED L. MAIN
Euclid Division

Assisted by William A. Fugenschuh
General Motors Institute

Pin deflection reduces bearing efficiency

this point, a particular problem will be given involving a pin joint used to connect the hydraulically operated steering-jack mechanism with the scraper draw-bar on a Euclid S-7, 7-yard capacity, overhung-engine scraper (Fig. 1).

After the first pilot model of the 7-yard scraper was built, the unit was sent to the General Motors Proving Ground at Milford, Michigan, for extensive tests of sustained heavy-duty operation. The tests were designed to reveal potential trouble spots which could not be determined by experimental methods. After being tested for approximately 450 hours, the unit was returned, disassembled, and then inspected. Among other checks, a thorough analysis was made of the wear conditions in all critical pin joints to determine possible desired changes which would be extended to improve the entire line of new overhung-engine scrapers then under design.

The wear pattern (Fig. 1) of the steering-jack pin-joint connection was measured, and the diameters at various locations were tabulated (Table I). The wear pattern clearly indicated that the steel pin had deflected excessively and had caused excessive bearing stresses on the outer edge of the bushing and the inner edges of the supporting "ears."

Calculations made of the bending stresses and deflection using uniformly distributed loads indicated that both the bending stress and deflection were of sufficient magnitude to be considered in the pin design. Because determination of actual pin deflections and bearing stresses in the pin joint would require an involved iteration process, a simpler method of pin analysis and design was desired.

To facilitate calculations in further design and development of the pin, bearing loads were assumed to be concentrated at the centerline of the bearing surfaces (Fig. 2). This assumption meant that the pin deflections resulting from these concentrated loads could be readily calculated if the distance between the applied loads were known. Pin diameters could likewise be determined based upon given length and unit deflection (in. per in.) values.

The bending stress in the pin can be used as a criterion for limiting pin deflection to desired values. An expression for the maximum bending stress in the pin is possible in terms of pin diameter, length, and applied load. If the bearing load is considered to be distributed uniformly across the bearing surface, an expression for bearing stress can be established in terms of bearing length, pin diameter, and applied load. These expressions can be solved simultaneously by either analytical or graphical means to establish optimum pin diameter and length for a given set of conditions.

In determining the optimum pin diameters for various applications, actual tests were made on pins designed to bending stress limits based on concentrated loads. From these tests design criteria were developed for insuring pin joints which provided satisfactory bearing qualities characterized by minimum wear and bending.

EAR BORE DIAMETERS
AS MEASURED
B/P SPECIFICATION = 1.625/1.627

LOCATION	D_1	D_2
DIAM A	1.644	1.637
DIAM B	1.644	1.636
DIAM C	1.671	1.645
DIAM E	1.646	1.633
DIAM F	1.643	1.633
DIAM G	1.643	1.633

JSHING BORE DIAMETERS
AS MEASURED
B/P SPECIFICATION = 1.633/1.637

LOCATION	D_1	D_2
DIAM H	1.645	1.643
DIAM J	1.639	1.637
DIAM K	1.650	1.642

Table I—This Table summarizes the diameters measured at various points along the wear pattern (Fig. 1) of the steering-jack pin-joint connection. The *B/P* specification refers to the tolerance dimensions which would be specified on a blueprint showing details of the pin-joint.

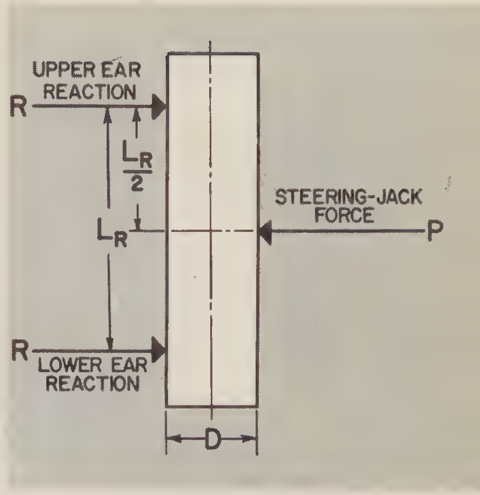


Fig. 2—The bearing loads acting on the pin due to the steering-jack hydraulic force *P* and the reactions *R* of the pin's 2 supporting "ears" are concentrated at the centerline of the bearing surfaces. The distance between the reactions of the supporting "ears" is L_R.

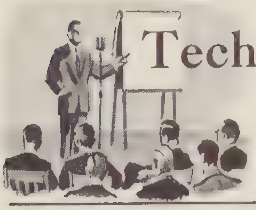
Problem

The problem, which is typical in nature to those encountered by design engineers at Euclid Division, is to determine the necessary diameter and length dimensions of a steel pin based on the following data:

- Effective steering-jack piston diameter = 5.50 in.
- Maximum steering-jack hydraulic pressure = 1,000 psi
- Maximum allowable bearing stress = 4,000 psi
- Maximum allowable bending stress = 30,000 psi.

The maximum allowable bending stress is used for material selection, as well as being a controlling factor in pin deflection.

Consideration must be given to the economics of the problem in that the minimum possible pin size is desirable. The solution to the problem, which will be presented in the January-February-March 1957 issue of the General Motors Engineering Journal, will be based on a graphical solution to establish optimum pin diameter and length.



Technical Presentations by GM Engineers

Speaking appearances by General Motors engineers are one of the ways in which GM makes available to the public information on current engineering developments. Engineers and technical personnel have presented papers and served as panel members of technical society meetings and have spoken in college classrooms and before civic organizations. Listed below are some of the recent speaking engagements filled by GM personnel. In some cases extra copies of the papers mentioned are available to engineering educators. Educators who wish to request copies of papers listed may write either to the GM organization where the author is located or to Educational Relations Section, Public Relations Staff, General Motors Technical Center, P.O. Box 177, North End Station, Detroit 2, Michigan.

GM engineers who have made recent presentations are as follows:

Aeronautical Engineering

Floyd G. Dougherty, chief, combustion group, fuel systems and components, Aircraft Engines Operations Department, Allison Division, before the Society of Automotive Engineers national aeronautic meeting, New York, New York, April 12; title: General Fuel Requirements for the Commercial Aircraft Gas Turbine Engine.

E. W. Pierce, section engineer, Spark Plug Engineering Department, AC Spark Plug Division, before the Cessna Aircraft Company, Wichita, Kansas, June 5; title: Aircraft Spark Plugs for Small Plane Users.

Automotive Engineering

William G. Mertens, chief metallurgist, Metallurgical Department, Detroit Transmission Division, before the 1956 National Passenger Car Body and Materials Meeting of the S.A.E., Detroit, Michigan, March 7; title: Automatic Transmission Gear Materials and Associated Problems, (**Frank Zuzick,** metallurgical engineer, Detroit Transmission Division, co-author of paper).

H. C. Kirtland, chief engineer, applications, Transmissions Engineering Department, Allison Division, before the Central Illinois Section of the S.A.E. earthmoving conference, Peoria, Illinois, April 4; title: What's Behind the Trend to Torqmatic Drives?

L. C. Lundstrom, assistant director, GM Proving Ground, before the Albuquerque Chapter of the American Society of Tool Engineers, Albuquerque, New Mexico, April 6; title: Experimental Engineering at GM Proving Ground; and before the S.A.E. summer meeting, Atlantic City, New Jersey, June 6; symposium participant, Wind and Rolling Resistance; speaker, title: Where Does All the Power Go?

G.A. Delaney, chief engineer, Pontiac Motor Division, before the Philadelphia Section of the S.A.E., Philadelphia, Pennsylvania, April 11, and before the Syracuse Section of the S.A.E., Syracuse, New York, May 22; title: Designing an Automobile.

Alfred L. Boegehold, manager, Research Activities, GM Research Staff, before the American Society for Testing Materials, Cleveland, Ohio, April 12; title: Materials in the Automobile of the Future.

D. C. Wilkerson, engineer, Transmission Development Department, GM Engineering Staff, before the Armstrong Engineering Association, Armstrong Cork Company, Lancaster, Pennsylvania, April 16; title: Why Didn't We Have Automatic Transmissions Sooner?

Zora Arkus-Duntov, research development engineer, Chevrolet Motor Division, before the Syracuse Chapter of the S.A.E., Syracuse, New York, April 17; title: The 1956 Corvette Sports Car.

Gil F. Roddewig, experimental engineer, Engineering Department, GMC Truck and Coach Division, before the Greater New York Safety Council, New York, New York, April 19; title: Design for Safety.

Darl F. Caris, head, Automotive Engines Department, GM Research Staff, before the Southern Section of the S.A.E., Los Angeles, California, April 23, and before the Northern Section of the S.A.E., San Francisco, California, April 25; title: What's Happening to Automotive Engines?

Richard L. Gross, project engineer, and **C. E. Murphy,** technician, Engineering Department, Guide Lamp Division, before the Optimist Club, Anderson, Indiana, April 26; title: Purpose and Demonstration of the T-3 System.

John Burnell, design engineer, Chevrolet Motor Division, before the Land of Lakes Region of the Sports Car Club of America, Minneapolis, Minnesota, April 26, and before the Salem Lutheran Church Men's Club, Detroit, Michigan, May 8; title: The 1956 Corvette Sports Car.

G. H. Vanator, assistant head, Noise and Vibration Laboratory, GM Proving Ground, before the Michigan Chapter of the Acoustical Society of America, Detroit, Michigan, May 8; title: Some Automotive Noise Problems.

E. F. Armstrong, chief engineer, General Motors of Canada, Ltd., and **Howard K. Gandelot,** engineer-in-charge, Vehicle Safety Section, GM Engineering Staff, before the Committee on Engineering, second annual meeting of the Canadian Highway Safety Conference, Winnipeg, Canada, May 8 and 9; consultants.

William H. Jackson, senior project engineer, Automotive Air Conditioning Department, Harrison Radiator Division, before the Buffalo Section of the Refrigeration Service Engineers Society, Buffalo, New York, May 11; title: Automotive Air Conditioning.

Mauri Rose, special engine and vehicle development engineer, Chevrolet Motor Division, before the Bedford High School Junior Chamber of Commerce, Bedford, Indiana, May 12; title: So I Learned From Racing; and before the Pittsburgh Section of the S.A.E., Oil City, Pennsylvania, May 16; title: The Challenge of Stock Car Racing to the Automotive Engineer.

A. Robert Colangelo, project engineer, Automotive Air Conditioning Department, Harrison Radiator Division, before the Lockport Junior Chamber of Commerce, Lockport, New York, May 23; title: Air Conditioning as Applied to Automotive Installation.

Howard K. Gandelot, engineer-in-

charge, Vehicle Safety Section, GM Engineering Staff, before the Traffic Police Administration Training Program, Traffic Institute, Northwestern University, Evanston, Illinois, May 23; title: Automotive Engineering in the Highway Transportation System; and before the Regional Traffic Safety Conference, President's Committee for Traffic Safety, Chicago, Illinois, May 23 and 24; consultant, Engineering for Traffic Safety Workshop; and before the S.A.E. summer meeting, Atlantic City, New Jersey, June 5; participant, Industry Report on Automotive Safety Research.

R. E. Kaufman, assistant staff engineer, Chevrolet Motor Division, before the Canadian Section of the S.A.E., Oshawa, Canada, May 25; title: A New Automatic Transmission for Heavy-Duty Chevrolet Trucks.

LaVerne B. Ragsdale, staff engineer, Product Engineering Department, Ternstedt Division, before the S.A.E. summer meeting, Atlantic City, New Jersey, June 4; title: Seat Adjusters.

Joseph B. Bidwell, head, and **Robert E. Owen,** assistant head, Engineering Mechanics Department, GM Research Staff, before the S.A.E. summer meeting, Atlantic City, New Jersey, June 5; title: The Experimental Chassis for the Firebird II.

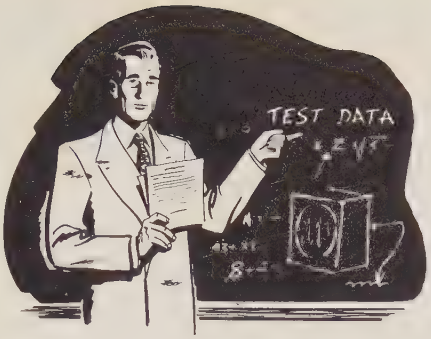
G. Harry, staff engineer, Automotive Engineering Department, AC Spark Plug Division, before the S.A.E. summer meeting, Atlantic City, New Jersey, June 5; title: Fundamentals of Fuel Pump Operation.

N. A. Hunstad, assistant head, **Theodore Selby,** research chemist, and **Robert Osborne,** research engineer, Fuels and Lubricants Department, GM Research Staff, before the S.A.E. summer meeting, Atlantic City, New Jersey, June 5; title: The Present Status of Automotive Transmission Fluid, Type A.

Richard A. Randall, research engineer, Fuels and Lubricants Department, GM Research Staff, before the S.A.E. summer meeting, Atlantic City, New Jersey, June 5; title: Automotive Fuel Pumps—a Fundamental Study of Their Performance.

Ken A. Stonex, head, Technical Data Department, GM Proving Ground, before the S.A.E. summer meeting, Atlantic City, New Jersey, June 5; discussion of W. A. McConnell paper, Motion Sensitivity as a Guide to Road Design.

William A. Turunen, head, and **John**



S. Collman, assistant head, Gas Turbines Department, GM Research Staff, before the S.A.E. summer meeting, Atlantic City, New Jersey, June 5; title: The Regenerative Whirlfire Engine for the Firebird II.

A. F. Underwood, head, Mechanical Development Department, GM Research Staff, before the S.A.E. summer meeting, Atlantic City, New Jersey, June 5; title: A Concept of the Free Piston Engine for Automotive Use.

L. T. Flynn, truck engineer, Truck Engineering Department, GMC Truck and Coach Division, before the S.A.E. summer meeting, Atlantic City, New Jersey, June 7; discussion leader on ratios in transmissions and axles.

Verner P. Mathews, chief engineer, Buick Motor Division, before the student chapter of the S.A.E., General Motors Institute, Flint, Michigan, June 7; title: New Models and Their Development.

F. W. Cummings, administrative engineer, Product Engineering Department, Rochester Products Division, before the E. I. duPont de Nemours and Company, Wilmington, Delaware, June 12; title: Engineering Problems in Carburetor Development.

A. Fandrey, service engineer, Service Department, Rochester Products Division, before the E.I. duPont de Nemours and Company, Wilmington, Delaware, June 12; title: Theory of Carburetion.

John G. Coffin, senior experimental engineer, Chevrolet Motor Division, before the Society of Plastics Industry, New York, New York, June 13; title: Advances in Body Manufacturing Techniques.

Donald J. LaBelle, assistant truck engineer, Truck Engineering Department, GMC Truck and Coach Division, before the New England Truck Operators, Boston, Massachusetts, June 14; title: Air Suspension for Highway Tractor-Trailers.

Edward N. Cole, vice president of General Motors and general manager, Chevrolet Motor Division, before the Belsky Alumni Association, Detroit, Michigan, June 21; title; A Design for the Future.

J. A. Winters, supervisor, sales contact and technical data, Transmissions Engineering Department, Allison Division, before the Central Indiana Section of Professional Engineers, Indianapolis, Indiana, June 21; title: The Powermatic Transmission.

N. L. Haight, project engineer, Noise and Vibration Laboratory, GM Proving Ground, before the joint meeting of the Automobile Manufacturers Association and American Association of Motor Vehicle Administrators, Detroit, Michigan, June 26; title: Progress in Measurement and Reduction of Truck Exhaust Noise.

Electrical Engineering

I. M. Levy, consulting engineer, Engineering Department, Delco Products Division, before the American Society of Refrigerating Engineers, Evansville, Indiana, April 3; title: Fan Motors for Air Conditioning Applications.

John A. McDougal, military products engineer, Defense Engineering Department, AC Spark Plug Division, before the student chapter of the S.A.E., General Motors Institute, Flint, Michigan, May 14; title: Skysweeper.

D. P. Driftmier, sales engineer, Sales Department, and **W. E. Griner,** project engineer, Engineering Department, Guide Lamp Division, before the Anderson High School safety classes, Anderson, Indiana, May 24; title: Development of the Guide Autronic-Eye Automatic Headlamp Control.

Foundry Methods

R. V. Righter, plant manager, Danville Plant, Central Foundry Division, before the American Foundrymens Society, Indianapolis, Indiana, April 2; title: How to Meet the Challenge.

Harold G. Sieggreen, chief engineer, Central Foundry Division, before a Wayne State University engineering class, St. Clair Shores, Michigan, April 24; title: New Casting Techniques.

Alfred L. Boegehold, manager, Research Activities, **Ray Amala,** senior research metallurgist, Metallurgical De-

partment, and **Robert F. Thomson,** head, Metallurgical Department, GM Research Staff, before the 60th annual castings congress of the American Foundrymens Society, Atlantic City, New Jersey, May 9; title: The General Motors Blow-Hot Press Automatic Shell Molding Machine.

General Engineering

John M. Campbell, technical director, GM Research Staff, before the American Chemical Society, Detroit, Michigan, February 21; title: Human Relations in Industry.

Joseph M. Rodgers, project engineer, Engineering Department, Delco Products Division, before the student section of the American Institute of Electrical Engineers, University of Dayton, Dayton, Ohio, February 21; title: My Wife's Fur Coat and Engineering.

W. F. Martin, manufacturing manager, Manufacturing Department, Euclid Division, before the Berea Exchange Club, Berea, Ohio, February 22; title: American Road Building Needs.

Edward N. Cole, vice president of General Motors and general manager, Chevrolet Motor Division, before Saginaw Valley National Engineers Week meeting, Flint, Michigan, February 23; title: The Engineer's Hard Job of Making Life Easier.

W. D. McMaster, assistant head, Chemistry Department, GM Research Staff, before the Chemical Institute of Canada, Montreal, Canada, February 23; title: Problems: The Price of Progress.

T. M. Schierloh, technical manager, Service Department, Delco Products Division, before the Florida State National Industrial Service Association, Jacksonville, Florida, February 26; title: Motor Repair and Maintenance.

Howard W. Brandt, general manager, Rochester Products Division, before the Human Relations in Administration seminar, Cornell University, Ithaca, New York, April 3; title: The Manager's Role in a Decentralized Organization.

Francis E. Smith, senior staff assistant, Design and Drafting Department, Fisher Body Division, before the Drafting Teacher's Institute, Detroit, Michigan, April 7; title: Body Drafting as Practiced at the Fisher Body Division, General Motors Corporation.

William K. Norwick, executive assistant to the chief engineer, Fisher Body Division, before the Michigan Industrial Education Society Convention, Detroit, Michigan, April 14; title: Changing Concepts of Drafting Standards.

Charles Rose, Jr., special assignment to chief engineer on defense products, AC Spark Plug Division, before the senior engineering students of Pennsylvania State University, University Park, Pennsylvania, April 16, and before the senior engineering students of University of Michigan, Ann Arbor, Michigan, May 8; title: Creativity.

John M. Campbell, technical director, GM Research Staff, before the Lead Industries Association, St. Louis, Missouri, April 25; title: Outlook for Lead in the Automotive Industry.

Leonard E. A. Batz, project engineer, Design and Standards Section, AC Spark Plug Division, before the *Michigan Technic* key awards dinner, University of Michigan, Ann Arbor, Michigan, April 26; title: Engineering Law and Ethics.

Fred W. Sabur, administrative engineer, Product Engineering Department, Ternstedt Division, before The Ohio State University drafting professors and others, Columbus, Ohio, May 4; title: Shortcuts in Producing Production Drawings.

George W. Sierant, design group leader, Product Engineering Department, Ternstedt Division, before The Ohio State University drafting professors and others, Columbus, Ohio, May 4; title: Training of Draftsmen.

Russell T. Holmes, standards engineer, Automotive Engineering Department, AC Spark Plug Division, before the Pontiac Chapter of the American Society of Tool Engineers, Pontiac, Michigan, May 17; title: Unified Screw Threads Standards.

Howard L. Roat, director, Production Engineering Department, AC Spark Plug Division, before engineering students of Cornell University, Ithaca, New York, June 12; title: Applying Creativity to Engineering Problems.

Erik H. Halvarson, in charge of design fundamentals, Product Engineering Department, General Motors Institute, before the American Society of Mechanical Engineers semi-annual meeting sponsored by the Education Committee, Cleveland, Ohio, June 18; title: Engineering Design in the College Curriculum.

Earl D. Black, in charge of engineering drawing and kinematics, Product Engineering Department, General Motors Institute, before the American Society for Engineering Education summer school for teachers of engineering drawing, Iowa State College, Ames, Iowa, June 21; title: Motivation Needed in Teaching Engineering Drawing.

Industrial Engineering

Howard W. Brandt, general manager, Rochester Products Division, before the American Materials Handling Society, Rochester, New York, April 4; title: Top Management's View on Materials Handling.

Claude M. Willis, safety director, Safety Department, Delco Products Division, before the Foremen's Club of Cincinnati, Cincinnati, Ohio, April 12; title: Safety—Job Analysis—Plant Inspection—Accident Investigation—Layout and Arrangement—Housekeeping.

Lloyd T. Christensen, assistant director, Production Engineering Department, AC Spark Plug Division, before the 8th annual management clinic of the Society for the Advancement of Management, Detroit, Michigan, May 18; title: How to Set Up and Develop a Methods Program.

Manufacturing

Thomas W. Bakewell, supervisor, general and machine tool projects, Product Engineering Department, New Departure Division, before the American Society of Tool Engineers, Cincinnati, Ohio, April 10; title: Ball Bearings and Machine Tools.

S. F. Newman, senior project engineer, Electrical Department, Process Development Staff, before the Rubber and Plastics Committee, American Institute of Electrical Engineers, Akron, Ohio, April 9, and before the Machine Tool Forum, Westinghouse Electric Company, Buffalo, New York, April 18; title: Cypak Installation on Torus Vane Loader.

Leon J. Rose, senior production engineer, Production Engineering Activity, Fisher Body Division, before the American Welding Society spring meeting, Buffalo, New York, May 8; title: Application of Safe Welding Practices.

Charles R. Cory, senior engineer in charge of designing and checking fixtures, Die Engineering Activity, Fisher Body Division, before the local chapter

of the American Society for Metals, Trenton, New Jersey, May 23; title: Economic Factors in Die Engineering.

Willard O. Emmons, director of research, Commercial Products Research, Harrison Radiator Division, before the S.A.E. summer meeting, Atlantic City, New Jersey, June 5; title: All Aluminum Brazed Heat Transfer Equipment.

K. B. Valentine, project engineer, Product Engineering Department, Pontiac Motor Division, before the first annual conference on tooling and materials conducted by Wayne State University, Detroit Board of Commerce, Engineering Society of Detroit, American Society of Tool Engineers, and American Society for Metals, Detroit, Michigan, June 14; moderator, panel discussion, New Applications and Process Developments with Aluminum and Its Impact on Tooling.

Research

Ralph J. Wirshing, head, Chemistry Department, GM Research Staff, before the American Chemical Society, Dallas, Texas, April 10; title: The Effect of Surface Contaminants on the Corrosion Resistance of Painted Steel.

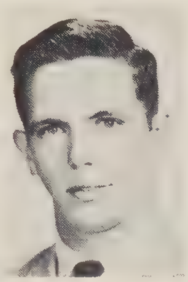
Ray Gallant, supervisor, engineering laboratory, Chevrolet Motor Division, before the Instrument Society of America, Detroit, Michigan, April 19; title: Instrumentation Techniques in Automotive Engine Development.

R. W. Smith, supervisor, physics and metallurgical laboratory, Research Department, AC Spark Plug Division, before the Michigan College Chemistry Teachers' Association, Flint, Michigan, May 12; title: Use of the Spectrograph.

A. F. Welch, assistant department head, Instrument Section, Technical Facilities and Services Department, GM Research Staff, before the Horological Institute annual meeting, Detroit, Michigan, May 20; title: Time in Automotive Research.

Farno Green, senior research physicist, Physics and Instrumentation Department, GM Research Staff, before the American Nuclear Society, Chicago, Illinois, June 6 to 8; title: Increased Yields of MN^{54}, I^{125}, and I^{130} with a 22 Mev Proton Cyclotron, (with John Martin).

Contributors to Oct.-Nov.-Dec. 1956 Issue of General Motors ENGINEERING JOURNAL

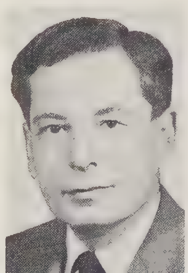


WILLIAM L. ALDRICH, JR., contributor of "Matching Compression Ratio and Spark Advance to Engine Octane Requirements," is a project engineer in the Engineering Department of Pontiac Motor Division.

He joined this Division in February 1952 as a junior engineer. His automotive experience at Pontiac Motor has included many phases of vehicle performance testing and development. For the past year Mr. Aldrich has been engaged in the development of combustion chambers and selection of distributor advances for V-8 engines. This work has supplied the information from which his paper is drawn.

After attending the University of Massachusetts for 1 year, he transferred to the University of Michigan, where he was graduated with the B.S.M.E. degree in 1952. While attending the University of Michigan, he received a commission as Second Lieutenant, U. S. Army (Ordnance), and he is now a First Lieutenant in the active reserves. Previously he served in the U.S. Navy from 1944 to 1946.

Mr. Aldrich is a member of the Society of Automotive Engineers and the Michigan Society of Professional Engineers.



EGON BENESI, contributor of "Design of a Centrifugal Filmer for the Ultraviolet Irradiation of Liquids," is a senior research engineer with the GM Research Staff.

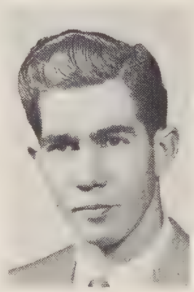
Currently his work includes research investigations into vibration and balance problems connected with automotive engine components and related parts. He also is concerned with fatigue and stress studies, as well as problems in dynamics of machines.

Previously Mr. Benesi was concerned primarily with the design and development of the Centrifilmer, of which he writes. He also has been involved in conducting a variety of torsional vibration studies of automotive crankshafts and automatic transmissions, as well as static bending tests on automotive crankshafts.

Mr. Benesi joined General Motors in 1935 as a mathematician with the Structure and Suspension Development Group of the GM Engineering Staff. In 1936 he transferred to the Research Staff as a mathematician.

He was graduated from the Vienna Technical University in 1932 with the degree equivalent to the master of mechanical engineering. Before joining General Motors, he worked for Austrofiat in Vienna.

Mr. Benesi is a member of the Industrial Mathematics Society.



JOHN G. COFFIN, contributor of "Engineers Set Serviceability Standards for Reinforced Plastic Automobile Bodies," is a test engineer with Chevrolet Motor Division at General Motors Proving Ground, Milford, Michigan.

Having received the B.S.E. degree from University of Michigan in 1948, Mr. Coffin joined GM as a college graduate-in-training at Cadillac Motor Car Division and was promoted to process engineer in 1950. In 1951 he transferred to Chevrolet's Central Office as assistant metallurgical engineer and became senior experimental engineer at Chevrolet's Flint assembly plant in January 1956. He assumed his present position in July 1956.

Contributors' backgrounds vary greatly in detail but each has achieved a technical responsibility in the field in which he writes.

Mr. Coffin's current work entails the analysis of appearance, function, and durability of production and proposed automotive passenger car and truck parts. As assistant metallurgical engineer at Chevrolet he participated in the selection of materials for all vehicle components, of both metallic and non-metallic composition. He was concerned also with specification development related to reinforced plastics for the Corvette body, including establishment of bonding, patching, and field repair materials and procedures involved in the application of reinforced plastics for automotive use.

Mr. Coffin is a member of the S.A.E., the Engineering Society of Detroit, and a committee participant in the American Society of Testing Materials. He is chairman of the General Motors Rubber and Plastics Committee.

Mr. Coffin has presented several papers and participated in numerous technical discussions before the S.A.E., the Society of the Plastics Industry, and other groups on the properties and applications of various plastic materials used by the automotive industry, both directly as parts on finished products and indirectly in manufacturing operations.

WILLIAM J. ELLIOTT, co-contributor of the problem "Determine the Overall Length of a Rigid Tube Connecting 2 Points on a Gas Turbine Engine" and the solution appearing in this issue, is a project engineer working on engineering calculations at Allison Division.

His current work with Allison entails the development of a formula translating system for the IBM 704 electronic digital computer. The formula translating system is a digital computer programming method in which equations required for the solution to a problem are first punched into IBM cards. The equations are then read from the cards directly into the "memory unit" of the computer, where they are translated, compiled, and assembled into a machine code program.

His previous projects have also concerned work with digital computation systems; he assisted in the development of the Allison Computer Operating Mode (ACOM), a floating decimal, 2-address interpretive system, for the IBM 701 and development of a subroutines library for this system. Subroutines are groups of instructions which may be repeated many times during the course of a problem's solution. He also developed the Engineering Automatic System for Solving Equations (EASE), a symbolic compiling and assembly program for the IBM 650.

Mr. Elliott attended Western Michigan College, graduating with the B.S. degree in 1952. Serving with the United States Air Force from October 1952 to October 1953 as a Second Lieutenant, he specialized in digital computation.

He joined Allison Division in 1953 as a detail engineer in the Machine Calculations Section and was promoted to his present position in 1955.

EDWARD R. FITZPATRICK, co-contributor of "Weight Control: a Vital Factor in Body Engineering," has been engineer-in-charge of the Engineering Standards Department of Fisher Body Division since 1948. This Department, which he supervises, is responsible for obtaining product costs of new proposals and for estimating weights of forward models.

After studying engineering at the University of Detroit, Mr. Fitzpatrick joined Fisher Body as a clerk in the Export Department in 1938. Having transferred to Fisher's Engineering Department, he was made supervisor of weight analysis in 1943. This position involved the estimating of weights an classification of materials of variou military products. Such data were sub sequently used to obtain priorities fo required materials under the govern ment's Controlled Material Plan durin World War II. In 1945 Mr. Fitzpatric became assistant section engineer; i this position he continued doing con trolled material work. During this post war time material analysis was used fo automotive rather than defense product as background information for overal production planning in GM's use o strategic materials in short supply.

He became assistant engineer-in-charg of the Engineering Standards Departmen in 1947 and was promoted to his presen position the next year.

Mr. Fitzpatrick is a member of th S.A.E. He is chairman of the editin sub-group of the General Motors Draftin Standards Sub-Committee. The Draftin Standards Sub-Committee, under th GM Engineering Standards Committee is responsible for the study, evaluation and correlation of drafting standard throughout General Motors.

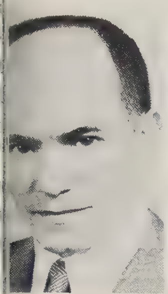
The General Motors Engineering Journal is a publication designed primarily for use by college and university educators in the fields of engineering and the sciences. Educators in these categories may, upon request, be placed on the mailing list to receive copies regularly. Classroom quantities also can be supplied regularly or for special purposes, upon request to the Educational Relations Section, General Motors.

ERIK H. HALVARSON, co-contributor of th problem "Determin the Overall Length of Rigid Tube Connectin 2 Points on a Gas Tur bine Engine" and th solution appearing i this issue, is a membe of the Product Engi neering Department at General Motor Institute.

Mr. Halvarson entered General Motor Institute, Flint, Michigan, in 1940 as co-operative student sponsored by Alliso Division. From 1943 to 1944 Mr Halvarson worked at Allison full time a a junior engineer in the Experimenta Bearing Test Department. He serve with the United States Army from 194 to 1946, specializing in photographi work.

On his return from military servic he joined the faculty of General Motor Institute. Continuing his studies an research, he received the Bachelor o Industrial Engineering degree in 195 In his present position in the Produc Engineering Department of the Institut he is in charge of the basic engineerin design courses.

Mr. Halvarson's technical society membership includes the Society of Automotive Engineers and the American Society of Mechanical Engineers. In the latter organization, he serves on the General Committee, Machine Design Division.



EPHRAIM M. HOWARD, contributor of "A Program for the Developmental Testing of Turbo-Jet Aircraft Engines," is a senior project engineer at Allison Division, where he is currently working on the modification of ambient test cells to accommodate the new Allison model 700 engine.

He joined Allison in March 1954 as a senior experimental engineer and in July 1955 transferred to the Plant Engineering Department to work on new test cells in the combustor and fluid dynamics laboratory of the turbo-jet facilities.

Mr. Howard was granted the B.S. degree in aeronautical engineering from Wayne State University, Detroit, Michigan, in 1946 and the M.S.E. degree from the University of Michigan in 1947.

Previous to joining GM, Mr. Howard worked as manager of the ram jet branch of the engine test facility of Arnold Engineering Development Center in Tennessee and as an aeronautical engineer and research scientist with the Lewis Flight Propulsion Laboratory, National Advisory Committee for Aeronautics, Cleveland, Ohio. Having entered the U.S. Army in 1942, Mr. Howard transferred to the U.S. Air Force and from 1943 to 1945 was a staff officer in charge of coordination of troop carrier aircraft and glider maintenance and glider assembly. He was separated in 1945 with the rank of Captain.

Mr. Howard is a member of the S.A.E., an Associate Fellow of the Institute of the Aeronautical Sciences, and was founding chairman of the Institute's Indianapolis Section. He also is a member of Sigma Rho Tau, honorary society.

His published papers cover the subjects of organizational management, personal counselling, ram-jet and turbo-jet analysis studies and developmental tests, chemical warfare, helicopters, wind tunnel design, and supersonic propeller studies.

CHARLES E. HUGGINS, contributor of "Electrical Controls Make Industrial, Gas-Fired, Special Atmosphere Furnaces Safe," is general supervisor of the Process Department of the Industrial Motor Plant, Delco Products Division, Dayton, Ohio.

As general supervisor, Mr. Huggins' work entails production planning of equipment, materials handling, and layout for the Industrial Motor Plant. At this location, Delco Products manufactures industrial motors from 1 hp to 150 hp and a-c and d-c generators of 10 kw to 200 kw. This plant also produces motors and blowers for locomotives and laminated steel rotors and stators for fractional and hermetic motors. Mr. Huggins' former projects have included oven and furnace controls and industrial motor test facilities, and his article illustrates one phase of this program of industrial safety as applied to gas-fired, special atmosphere furnaces.

Mr. Huggins joined Delco Products Division of General Motors in 1947 as a control engineer in the Process Department. He was promoted to his present position in January 1956. Before joining GM, he was employed at Curtiss-Wright Corporation, Curtiss Electric Propeller Division.

Mr. Huggins was granted the B.S. degree in electrical engineering from Rose Polytechnic Institute in 1943. He is a member of the American Institute of Electrical Engineers.

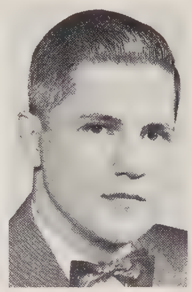
WALTER C. MIDDLETON, contributor of "Some Problems Encountered in Exploiting Inventions" and this issue's "Notes About Inventions and Inventors," is a patent attorney with the General Motors Central Office Patent Section in Detroit.

He joined the Patent Section in July 1952, having had over 25 years' experience in patent activities with such corporations as Bell Telephone Laboratories and Western Union Telegraph Company and patent law firms in New York City.

In his capacity as patent attorney Mr. Middleton's work with GM entails supervision of patent applications for inventions developed by GM employes. He also conducts infringement investigations on new or changed devices or processes and studies to determine the scope and validity of patents which appear to be pertinent to devices which are used in production relating to automatic transmissions.

Mr. Middleton studied engineering at Alabama Polytechnic Institute, Auburn, Alabama, and was granted the B.S. degree in electrical engineering from the Institute in 1923. He received the LL.B. degree in 1928 from the law school of St. Lawrence University, Brooklyn, New York.

Mr. Middleton is a member of the bar of the States of New York and Michigan.



FRANCIS A. WICKERT, co-contributor of "Weight Control: a Vital Factor in Body Engineering," is supervisor of material and weight analysis in the Engineering Standards Department, Body Engineering Section, of Fisher Body Division.

He joined Fisher Body in 1943 as a clerk on material and production control in the Aircraft Engineering Department. He was promoted to weight analyst in 1946, to technical writer in 1952, and to his present position in March 1956. While a technical writer, Mr. Wickert was responsible for incorporating various engineering procedures and standards in the Fisher Body Engineering Manual. Other writing assignments included the preparation of guidance booklets on body engineering practices at Fisher Body. The booklets were written primarily for high school students majoring in drafting and engineering graduates to acquaint them with career opportunities in the field of automotive body engineering.

Mr. Wickert studied accounting at the University of Detroit and mechanical engineering at the Detroit Institute of Technology. In 1949 the Design and Engineering Institute in Detroit awarded him a diploma in automobile body design.

From 1944 to 1946 Mr. Wickert served with the United States Army in the European Theater of Operations.

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3 May-June 1956
4 July-August-September 1956
5 October-November-December 1956

Example: 2-38 means page 38 of the March-April 1956 issue.

Abbreviations

(CP) Classroom problem
(Ed) Editorial—always appears on unnumbered inside front cover
(I) Inventor
(P) Portrait

A

BACK ISSUES: Readers may obtain back issues of the GENERAL MOTORS ENGINEERING JOURNAL as available upon request to the Educational Relations Section.

B

C

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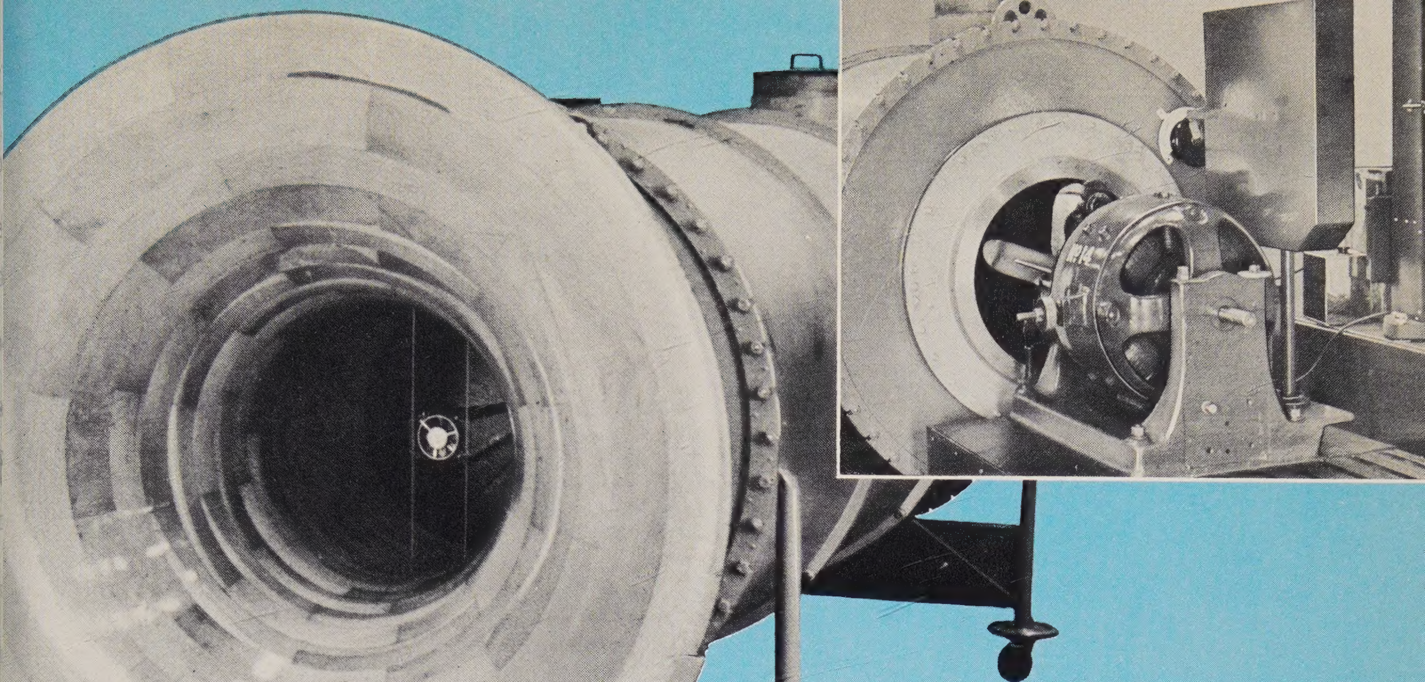

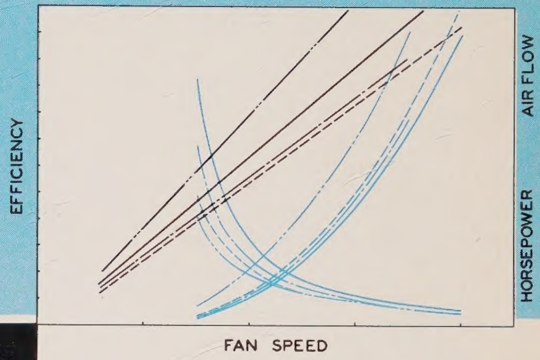

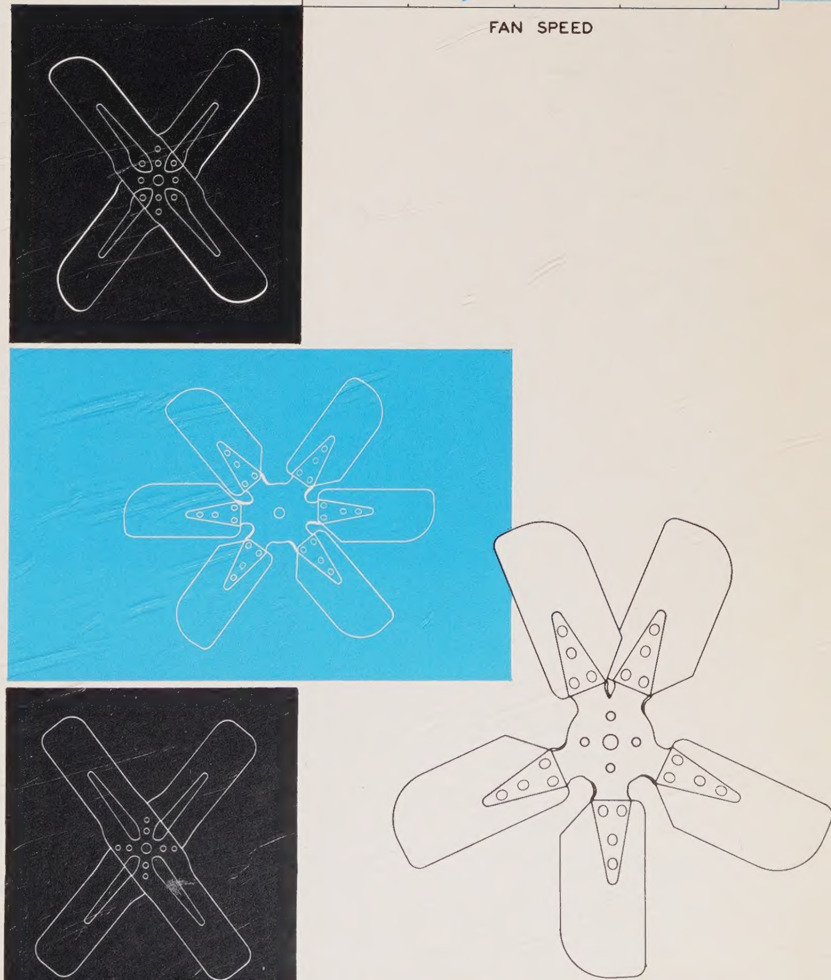

AUTOMOTIVE FAN TEST

This smooth-edge orifice is the entering end of a 20-in. wind tunnel used at Pontiac Motor Division's engineering laboratories. The orifice is attached to a plenum chamber 4 ft in diameter by 13 ft long. Mounted in the center of the orifice is a vane-type anemometer, which was used in determining the orifice coefficient.

This wind tunnel is one of several air-flow measuring devices used in developmental work on automotive components. For example, the inset view shows a fan for automotive engine cooling undergoing a test. The fan is located in a shroud at the opposite end of the tunnel and is coupled to a d-c electric dynamometer. Also shown is the micromanometer used to measure pressure drop across the orifice. Through the years, fan performance has had to keep pace with improvements in automotive engine design. Thus, through the use of equipment like this, characteristic air flow, efficiency, and horsepower curves are obtained with variable fan pressure restrictions. With these data, specific fan designs and installations are compared for performance, resulting in a final version which is satisfactory from the standpoints of fan performance, noise, power requirements, overall engine performance, and dependability.

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